TRIP REPORTS—PART I

IMPROVED PASSENGER EQUIPMENT EVALUATION PROGRAM

FEDERAL RAILROAD ADMINISTRATION

Braking Systems

WORKING PAPERS - PART 3

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TRIP REPORT

FEDERAL RAILROAD ADMINISTRATION
&
NATIONAL RAILROAD PASSENGER CORPORATION
(AMTRAK)

EUROPEAN VISIT
TO
EVALUATE CANDIDATE PASSENGER
TRAIN EQUIPMENT

DEPARTMENT OF TRANSPORTATION
UNITED STATES OF AMERICA

SEPTEMBER 9, 1975 to OCTOBER 6, 1975

MARCH 17, 1976

1.0 Introduction

A number of new foreign train systems are now or soon will be available for possible applications on U.S. railroads. Some of these trains are potential candidates for use by AMTRAK in the interim period before the development of the U.S. Improved Passenger Train (IPT). In addition, some of these trains employ components and subsystems that are highly desirable for application in U.S. trains, i.e., tilt body, trucks, drive systems, etc.

The Federal Railroad Administration and AMTRAK jointly plan to conduct an evaluation of all of the new or prototype foreign passenger trains that are likely candidates for use in the U.S. The results of this program will provide AMTRAK, and other railroad systems in the U.S., with in-depth knowledge of existing train systems, components, and sub-systems that could be used in the U.S. in the near future. The evaluation will also indicate the degree of modification, if any, required for each system to satisfy the U.S. requirements. As now envisioned, the program will cover a period of approximately 2 years. During the first phase, all candidate train systems will be involved in a screening process in which a team of FRA and contractor personnel will make technical studies of all systems and select from them a number for subsequent detailed evaluation in the U.S. During the first part of the program, the FRA team will make visits to each train supplier's facility for inspection and some limited testing, but rely primarily on technical data provided by each train supplier.

Between September 9, 1975, and October 6, 1975; three U.S. Rail Officials visited the various foreign suppliers to assess their interest in participating in the above outlined program. The delegation also attended the IRCA/UIC International Railway Congress, held in Bologna, Italy, from September 29, 1975, to October 4, 1975.

1.1 Delegation

The U.S. delegation consisted of three members. Their names and titles are as follows:

Mr. Myles B. Mitchell
Director, Office of Passenger Systems Research & Development (FRA)

Mr. M. Clifford Gannett
Acting Chief, Passenger Equipment Division (FRA)

Mr. Frank S. King
Corporate Vice President
National Railroad Passenger Corporation (AMTRAK)

1.2 Agenda

The agenda for the various visits was as follows:

1. England - Ride the High Speed Train (HST), discuss the Advanced Passenger Train (APT), train speed vs. track improvements, railroad electrification and assess England's interest in participating in the Candidate Passenger Train Evaluation Program.

2. France - Ride the experimental prototype turbotrain - TGV-1, discuss the new Z7001 electric train, the Y-32 truck design and assess France's interest in participating in the Candidate Passenger Train Evaluation Program.

3. Germany - Discuss railroad electrification and ET 403 train system with the Minister of Transport in Frankfurt. Visit the Frankfurt coach works and see various passenger train coach interiors. Ride the ET-403 from Munich to Ausburg, discuss traction motor designs, track forces, and visit the locomotive and transit car workshops. Visit Knorr Brake in Munich to discuss LTV/SIG brake problems, Knorr brake systems on AMTRAK trains, and tour workshop.

4. Sweden - Visit ASEA in Vasteras to discuss and ride the R-3 locomotive, discuss railroad electrification, traction motors, transformer coolants, and tour the workshop.

5. Switzerland - Ride and discuss the Swiss four-car tilt train and evaluate SIG's interest in participating in the Candidate Passenger Train Evaluation Program.

6. Italy - Visit Fiat to discuss and ride the Fiat tilt train, discuss railroad electrification, locomotives, and assess Fiat's interest in participating in the Candidate Passenger Train Evaluation Program. Attend the IRCA/UIC International Railway Congress in Bologna.

1.3 Itinerary

September 9 - Tuesday

7:30 p.m.	Leave Washington, D.C. for London

September 10 - 10 Wednesday

7:30 a.m.	Arrive London and settle in hotel
2:30 p.m. - 5:30 p.m.	Initial meetings with British Rail Engineering

September 11 - Thursday

7:50 a.m. - 9:51 a.m.	Train to Derby
10:00 a.m. - 12:30 p.m.	Discussion on track structures, electrification, APT and HST
2:00 p.m. - 3:30 p.m.	Tour of workshop
3:45 p.m. - 5:50 p.m.	Return to London by train

September 12 - Friday

9:30 a.m. - 10:10 a.m.	Meeting at London/Paddington Station on HST demonstration test run
10:15 a.m. - 1:00 p.m.	High speed test run from London to Bristol on HST. Technical discussion about train performance conducted during ride
3:00 p.m. - 6:30 p.m.	Return to London on conventional train

September 13 - Saturday

9:05 a.m.	Flight from London to Paris
10:30 a.m.	Arrive at Paris and settle in hotel
2:00 p.m. - 4:30 p.m.	Discussions with DGA and Mors Materiel on French Turbotrains and electrification

September 14 - Sunday

Substantive day

September 15 - Monday

7:52 a.m. - 12:15 p.m.	Leave Paris for Bordeaux on TEE train L'Etendard. Discuss track structures, electrification and train systems.
1:30 p.m. - 4:30 p.m.	Ride TGV-001 on test track
5:00 p.m. - 10:00 p.m.	Return to Paris from Bordeaux via conventional train

September 16 - Tuesday

9:15 a.m. - 1:00 p.m.	Meeting with SNCF and MTE to discuss TGV, Z-7001, and train modifications required for U.S. use
3:40 p.m.	Leave hotel for train station
5:20 p.m.	Leave Paris for Frankfurt by train
11:18 p.m.	Arrive Frankfurt and settle in hotel

September 17 - Wednesday

9:00 a.m. - 10:30 a.m.	Meeting with German Federal Railways to discuss electrically propelled, multiple unit trains, E-403 train and electrification
10:30 a.m. - 12:30 p.m.	Tour passenger train workshop
3:10 p.m.	Leave Frankfurt for Munich on TEE Train pulled by 403 locomotive
7:12 p.m.	Arrive Munich and settle in hotel

September 18 - Thursday

8:00 a.m. - 9:45 a.m.	Test ride on E-403 train to Ausburg - return on conventional train
10:00 a.m. - 12:30 p.m.	Meeting with Electrical Department of DB to discuss locomotives, traction motors, electrification, active suspension systems, and rail flaw detectors
2:00 p.m. - 2:30 p.m.	Short visit with Herr Ebeling, Acting President of DB, Munich
3:00 p.m. - 5:30 p.m.	Tour of locomotive and transit car workshops

September 19 - Friday

8:15 a.m.	Leave for Knorr
9:00 a.m. - 10:00 a.m.	Meeting with LTV and Knorr on LTV/SIG trucks program
10:00 a.m. - 11:00 a.m.	Meet with Knorr personnel and discuss brake systems
11:00 a.m. - 1:00 p.m.	Plant tour
2:30 p.m. - 4:30 p.m.	Continue plant tour and wrap-up meeting

September 20 - Saturday

Substantive day

September 21 - Sunday

Substantive day

6:00 p.m.	Leave for Stockholm by air
11:05 p.m.	Arrive Stockholm and drive to Vasteras
12:30 a.m.	Settle in hotel

September 22 - Monday

8:15 a.m. - 12:00	Meet with ASEA personnel to discuss thyristor locomotives, multiple-unit train sets, railroad electrification, traction motors, and active suspension system technology and control
1:00 p.m. to 4:00 p.m.	Tour workshops and see traction motor construction, electronic shop and control system fabrication technique
5:00 p.m. - 6:00 p.m.	Car trip to railroad station to catch ride on R-3 locomotive
6:30 p.m. - 8:00 p.m.	Ride R-3 locomotive and transit car to Stockholm
8:30 p.m.	Settle in hotel

September 23 - Tuesday

7:15 a.m. - 7:50 a.m.	Car to airport
8:50 a.m.	Flight from Stockholm
11:15 a.m.	Arrive Zurich and drive to Shaffhausen
2:00 p.m. - 5:00 p.m.	Visit SIG plant in Neuhausen. Discuss tilt train and tour facilities

September 24 - Wednesday

7:45 a.m.	Take train from Shaffhausen to Bern
10:00 a.m. - 12:15 a.m.	Four-car test train ride
2:00 p.m. - 4:00 p.m.	Test train ride
4:00 p.m. - 6:55 p.m.	Conventional train return to Shaffhausen

September 25 - Thursday

8:00 a.m. - 2:00 p.m.	Visited SIG for further discussions on tilt train, hydraulic control systems, LTV/SIG Metroliner Truck Program and SIG interest in Candidate Passenger Train Evaluation Program
3:18 a.m. - 9:55 p.m.	Train from Shaffhausen to Milano, Italy
10:15 p.m.	Settle in hotel

September 26 - Friday

8:30 a.m. - 10:25 a.m.	Car to Turin (railroad strike)
10:30 a.m. - 12:30 p.m.	Visit Fiat plant and discuss tilt train, truck design, and Fiat's interest in Candidate Passenger Train Evaluation Program
2:30 p.m. - 7:00 p.m.	Fiat plant tour

September 27 - Saturday

Substantive day

September 28 - Sunday

11:00 a.m. - 2:15 p.m.	Auto from Turin to Bologna (railroad strike)
3:00 p.m.	Check in the IRCA/UIC International Railway Congress

September 29 - Monday

10:50 a.m. - 12:00 a.m.	Opening of IRCA/UIC Railway Congress
2:00 p.m. - 5:30 p.m.	Attend IRCA/UIC Congress
8:00 p.m.	Attend Chamber of Commerce of Bologna reception

September 30 - Tuesday

8:30 a.m. - 12:00	Attend IRCA/UIC Congress
2:00 p.m. - 4:00 p.m.	Attend IRCA/UIC Congress
6:30 p.m.	Delegates of Congress meet the Mayor of Bologna

October 1 - Wednesday

9:00 a.m. - 12:00	Attend IRCA/UIC Congress
2:00 p.m. - 6:30 p.m.	Attend IRCA/UIC Congress
8:30 p.m.	URRIFER (Rolling Stock builders) reception

October 2 - Thursday

9:00 a.m. - 6:00 p.m.	Technical visit to the works on the new Florence-Rome railroad line and ride Fiat tilt train

October 3 - Friday

8:45 a.m. - 12:30 p.m.	Attend IRCA/UIC Congress
2:00 p.m. - 6:00 p.m.	Attend IRCA/UIC Congress
8:00 p.m.	Official dinner for delegates

October 4 - Saturday

2:50 p.m.	Train to Rome
8:10 p.m.	Arrive in Rome

October 5 - Sunday

Substantive day

October 6 - Monday

9:15 a.m - 4:30 p.m.	Return to United States by air

2.0 Summary

A preliminary assessment of the foreign equipment evaluated provided sufficient justification to pursue the Candidate Passenger Train Evaluation Program further. All of the suppliers visited indicated a willingness to participate in the program. The following subparagraphs summarize the discussions held.

2.1 England

British Railway Engineering has two train systems under development. They are the High Speed Train (HST), geared for 125 mph operation; and the Advanced Passenger Train (APT), which was designed for an ultimate speed of 155 mph. The HST was built to fill the equipment needs prior to introduction of the APT. The APT will not be developed to run at speeds above 135 mph for several years as a result of recent engineering and economic studies.

The HST is a non-active suspension system, 2,250 horsepower per car diesel-powered train system. The first class car seats 48 persons, the second class 72 perons, the kitchen car 24 persons, and the buffet car 35 persons. A typical train consist is nine cars, two power cars and seven passenger cars. The train is comfortable riding, but the seats and aisles are narrow-making it non-desirable for U.S. utilization in its present configuration.

The APT is an active suspension electric train system. Originally, the APT was to have also had a gas turbine powered version, which was discarded due to mechanical problems. Three of the electric train versions will be built and tested between 1977 and 1978, with passenger demonstration service in late 1978. Because of the lagging development status of the APT, it is not a viable contender for U.S. evaluation in the near future.

Mr. Lawrence, Chairman of British Railway Engineering, expressed a willingness to provide equipment to test in the U.S. for evaluation purposes. He stated that it was his feeling that no major purchases would result from this activity, but that he was willing to participate never-the-less. The cost of modifying the test equipment for U.S. operation was also discussed and Chairman Lawrence expressed an interest in sharing the cost.

Pullman Standard representatives were visiting British Rail during the same period as our visit with the expressed interest in becoming the U.S. Licensee for all equipment built in the U.S. As of this date, no formal agreement has been signed.

2.2 France

The French have two train systems under development. They are the TGV-1 and the Z-7001. The SNCF has the ownership of the TGV, and the Z-7001 is still being developed for SNCF by MTE. The TGV is a gas turbine powered, five-car consist. The train system will ultimately be an eight to twelve-car consist, with a power car at each end; when it goes into service in 1980. The Z-7001 is currently a single-unit electric test car, used to develop new equipment for speeds up to 180 mph.

The SNCF and MTE have performed numerous studies related to designs of active suspension systems. They have concluded that they do not need such a system and, therefore, have dropped all work in this area.

Both SNCF and MTE expressed their willingness to cooperate on the Candidate Passenger Train Evaluation Program. They explained that they believe that they already have all of the test data we would need prior to bringing their equipment to the U.S. for evaluation and would make such data available to our engineers. They did state, however, that should additional tests be required in Europe, with our test equipment, they would make the train equipment available.

The SNCF indicated that it would be one year before the TGV could be transported to the U.S. for testing, and that all formal transactions would be through them. Their U.S. representative is DGA, Washington, D.C., and they are authorized to represent both SNCF and MTE.

2.3 Germany

The German Federal Railway does not have a "new" train system under development. Their experimental train E-403, currently in revenue demonstration service, does, however, represent the latest technology. The locomotive is thyristor controlled with cab signaling control with an automatic speed monitor which tracks allowable speeds versus actual speed. The traction motors are frame mounted to reduce unsprung weight and the braking system uses both disc and dynamics with the grids on the car body roof.

The train has a speed capability of 120 mph in revenue service, and has an active suspension system. The active suspension system, however, has not been used in revenue service because of the low-speed operation. They feel that the maintenance cost of operating the active suspension will not be beneficial until they start operating the speed at 150 mph in revenue service.

Although the subject of the Candidate Passenger Train Evaluation Program was not discussed in its full context, it was apparent that they were willing to cooperate in exchanging applicable technology.

In the meetings with Knorr Brake, Munich, there was a definite interest expressed as to its willingness to respond and cooperate on the program. Knorr has a large engineering and manufacturing facility in Munich and did a good job of displaying its capabilities.

2.4 Sweden

Sweden was visited for the express purpose of evaluating the ASEA separately excited traction motor locomotive (Rc-4). The visiting team took advantage of the opportunity to also discuss ASEA's knowledge and capabilities in the field of railroad electrification, traction motors, active suspension systems for passenger trains, and transformer working fluids.

AMTRAK has signed a lease/option agreement with ASEA for delivery of an Rc-4 test locomotive in July 1976. It is rated at 5000 continuous hp. It is geared for 103 mph maximum speed with an overspeed capability of 115 mph for short periods. The axle-loading is 23 U.S. tons.

2.5 Switzerland

The Swiss Industrial Company (SIG) has the prime contract for the manufacturing of a tilt passenger car for the Swiss Federal Railway. Currently, there are four such cars under test; hauled by an electrically powered locomotive at speeds up to 120 mph. The locomotive does not employ the car body tilt mechanism but uses roll bars, enabling it to negotiate the curves at high speeds.

The car body tilt mechanism is hydro-electric, with a Honeywell control system. The sensor for the first car is located in the locomotive, and in the car immediately ahead for each car thereafter. It is claimed that the tilt mechanism allows the equipped cars to negotiate curves at speeds 30 percent faster than similar cars not equipped with said system.

SIG expressed an interest in participating in the Candidate Passenger Train Evaluation Program and stated that we could have all four of their test cars for evaluation purposes after January 1, 1976. SIG has a signed license agreement with LTV, Dallas, Texas, for any and all components, systems, or trains developed by SIG for utilization within the United States and Canada.

2.6 Italy

Fiat has an electrically propelled, four car, tilt train consist that presently is undergoing tests at speeds up to 155 mph. Fiat states that the tilting mechanism allows this train to negotiate curves at speeds some 30-35 percent higher than those normally allowed with conventional rolling stock. The train is built of light alloy for reduced weight. The braking system not only employs dynamic braking, but also uses a pneumatic disc brake system and an emergency system using electro-magnetically operated shoes. The four car consist has a power unit at each end and seats a total of 175 passengers.

Dr. Ing. Renato Piccoli, senior official of Fiat's rail division, stated that his company wanted to participate in the Candidate Passenger Train Evaluation Program. Not only do they want to have their train system evaluated, but also any of their components or subsystems deemed applicable, especially their high-speed bogies. Fiat does not have a licensee agreement with any U.S. firm at this time.

3.0 Detailed Discussions

In-depth discussions were held iwth the various railroad personnel and supply industry personnel representing the countries visited. Some of the more salient points of these discussions are presented here-in.

3.1 England

3.1.1 Visit to British Rail Engineering, Ltd., and British Rail Board, London

September 10, 1975

Persons Contacted

Mr. Lawrence, Chairman, British Railway Engineering
Mr. Graham S. W. Calder, Chief Mechanical & Electrical Engineer, BRE
Mr. R. A. Powell, Manager of Commercial Services, BRE
Mr. David R. Meek, Director, Transmark

Mr. Lawrence stated that their engineering and economic studies indicated the top speed of the Advanced Passenger Train (APT) would be 135 mph. He said that discussions have been held with several United States car builders, but no decision has been made to date. At the time of our visit, Pullman Standard engineers were reviewing both APT and High Speed Train (HST) equipment. According to Mr. Lawrence, an HST prototype might be available in the future for testing in the United States. He indicated a willingness to participate in evaluation programs.

Mr. Calder indicated special points of interest concerning the APT. They are: the tubular axle design, the hydraulic kinetic brake, and the 9-degree tilt mechanism. The end buffing strength of the cars is 150-tons. Three electric APT prototypes will be built--scheduled for completion in 1980. The axle weight will be 17-tons.

3.1.2 Visit to British Rail Engineering (BRE) Research Center, Derby, England

September 11, 1975

Persons Contacted

Mr. Bruce G. Sephton, Traction Design Engineer, British Railway Board
Mr. John Stephenson, Truck Dynamics Engineer (BRE)
Mr. David Boocock, APT Project Engineer (BRE)

The British Railway is 30% electrified with a large quantity of concrete sleepers in main lines. The British said they feel the concrete slab is the most desirable rail support. The electrified lines are predominantly 25 kv 50 hz, but there are some 1500 DC.

The electrification of London-Manchester and Liverpool lines has been very successful, resulting in a 2% increase in ridership for each one mph increase in speed.

3.1.3 Demonstration Test Ride on HST from London to Bristol and Return

September 12, 1975

Persons Contacted

Mr. Sidney Ridgeway, Managing Director, BRE

Mr. L. E. Middleton, General Manager, BRE-Metro

Mr. Rowland Smith, Manager of Traction Department, GEC Diesels

Mr. Van der Sluys - Vice President - Operations Passenger Division

Mr. Patrick G. Welsh, Director of Marketing, Pullman-Standard

High Speed Train (HST)

The BRE made a comparison of diesel and gas-turbine operation and came to the conclusion the initial cost of the turbine is 2 to 2 1/2 dollars per horsepower, the fuel consumption is 1.7 times greater than a diesel, and the maintenance cost 2 to 3 times greater.

The HST train consists of nine units: two power-cars and seven coaches. The power-cars are at each end and weigh 70-tons, a 32-wire jumper cable connects the 2 power units. Each power unit is equipped with a 2250 hp Paxman diesel-engine that rotates at a top speed of 1500 rpm.

The traction motors are mounted to the truck frame and are equipped with a hollow shaft which permits a resilient coupling to the gear train. The AC current is rectified and controlled by thyristors and supplies DC motors.

The HST cars are 75-feet long, weight 33-tons, and are 8'10" wide. the coach-car seats 72 people. Trains are equipped with both all-electric diner cars and buffet cars. The diner car, equipped with Micro-wave ovens, draws 100 kw, and the buffet car 80 kw; coaches draw 40 kw. Each diesel powers an alternator that supplies 280 kw to a 480 volt trainline. The trainline is fed from one end at a time. The train can accelerate from 0 to 100 mph in 4.0 miles, to 120 mph in 7.5 miles, and to 125 mph in 10.0 miles. The cars are equipped with Mark III trucks designed with a rotary journal box and primary coil springs. The secondary consists of swing hangers and air bags with two air reservoirs. This is a proven design truck with good performance at a low maintenance cost. The wheels are provided with a worn profile. BRE expects to operate 200,000 miles between machinings. The trucks are provided with Gerling disc brakes and tread wipers.

On September 12th, we rode a prototype train to Bristol. We rode in the locomotive cab at a speed of 125 mph. It is expected that three prototypes will be built by October 1978.

Simulations that have been made indicated that on the 416-mile London-Glasgow line the scheduled times may be as follows:

	Top Speed	Trip Time
Conventional Train	100 mph	5'05"
HST	125 mph	4'55"
APT	120 mph	4'00"
APT	150 mph	3'49"

The undesirable features of the HST are:

1) high platform use only - no steps
2) narrow car, narrow aisle - 17"
3) low buff strength cars - 200-tons
4) toilets are not supplied with reservoir

3.2 France

3.2.1 Visit with DGA and Mors Materiel in Paris

September 13, 1975

Persons Contacted

Mr. Thomas Floyd, DGA International

Mr. Bernard Pellegrin, General Manager, Mors Materiel

On September 13, 1975, we met with Messrs. Pellegrin and Floyd to discuss the capability of Mors Materiel to design and fabricate electrical equipment. Mors Material furnished electrical control equipment used on the French RTG trains. Mors Materiel has a broad base of production of electrical equipment in France.

3.2.2 Demonstration Test Ride on TGV, Bordeaux

September 15, 1975

Persons Contacted

Mr. Raymond Garde, Chief Engineer, SNCF

Mr. Yves Machefert-Tassin, Chief Engineer, MTE

On September 15th, we traveled between Paris and Bordeaux in Grande Comfort cars. The distance between the cities is 352 miles, and was traveled in 4 hours and 05 minutes, with three intermediate stops. The top speed of the CoCo electric-locomotive was 125 mph.

Locomotive

The six-axle locomotive is equipped with one traction motor per truck. operates on 25 kv 50 hz, and produces approximately 6000 hp. The weight per axle is 21-tons. The gearing arrangement is such that the gear train can be changed from passenger to freight service by an operator in the cab. The locomotive is equipped with dynamic brakes. The truck secondary suspension consists of Metalastic springs similar to the GE E-60.

Cars

The Grande Comfort production cars operate on the French railroads. The cars are equipped with Y-28 trucks that are of a simple H-design with coil springs used for both primary and secondary suspension. These trucks and the later model Y-32 are considered adequate for speeds to 150 mph.

TGV

We rode the TGV test train south of Bordeaux. The train consisted of two turbo-powered cars and three passenger coaches, one used as an instrument car. The train, when placed in service between Paris and Lyon, will be electrically propelled. The cars are articulated. The train has been in test service for 3 years of high-speed running. The axle-loading is 16-tonnes.

During the test run on which we rode, braking tests were conducted from a top speed of 160 mph. There are two gas-turbines in each power car producing 1200 kw each.

The 3-year testing was used to evaluated:

a. Wear
b. Energy utilization
c. Adhesion
d. Comfort
e. Drag
f. Braking

There have been some 800 trials exceeding 250 km/hr, and 150 tests exceeding 200 km/hr.

Z-7001

The Z-7001 is an electrically propelled car used as a test bed for testing bogies and linear motor braking. The Y-225 truck is used under the TGV and the Y-226 under the Z-7001. The Y-225 has a truck mounted traction motor arrangement and the Y-226 a body mounted TM. The Z-7001 has made numerous tests exceeding 300 km/hr.

The linear motor brake has stopped the Z-7001 from 300 km/hr to 0 in 1.8 miles.

The TGV and Z-7001 were equipped with instrumented wheel sets to measure lateral forces. These forces measured 3-tonnes up to 300 km/hr. The wheel readings were transmitted by means of radio.

The TGV test train is equipped with Knorr disc brakes, reostatic brake, electro-magnetic and tread brakes.

It is anticipated the TGV equipment will go into service in 1980. The trains will consist of 8 or 12 cars with trainline power supplying approximately half of the axles in the train. The French anticipate operating these trains at 150 mph. The wheel profiles are of a worn wheel design and it is anticipated they will be turned every 100,000 miles.

3.2.3 Meeting with MTE and SNCF in Paris

September 16, 1975

Persons Contacted

Mr. Raymond Garde, Chief Engineer, SNCF
Mr. Henai Jullien, Director-General, MTE
Mr. Roger Helynch, Commercial Director, MTE
Mr. Yves Machefert-Tassin, Chief Engineer, MTE
Mr. Paul Treffort, Engineer, MTE
Mr. Thomas Floyd, DGA International

On September 16th, we met with Mr. Helynck of MTE and Mr. Harde of SNCF. It was indicated the TGV would be tested for one more year and, at that time, would be available to the United States. The wheels would have to be pressed slightly closer and the wheel profiles re-machined.

The French feel that the Y-32 model is an excellent high-speed truck and should be considered for high-speed, U.S. service.

We left Paris on a train to Metz at 5:20 p.m. Mr. King and Mr. Gannett rode the cab of a BoBo 15,000 locomotive. This locomotive is operated on this route at 180 km/hr. The 220-mile trip is made in 3 hours 25 minutes.

These locomotives are equipped with one motor per truck. After leaving Paris, one motor went off the line and the trip was made with one mot in operation. The train was brought up to top speed of 180 km/hr, and went into Metz on time. There are 50 of these locomotives in service and 300 on order.

The French use mineral oil as transformer coolant and have not experienced any difficulties.

3.3 Germany

3.3.1 Visit to German Federal Railways, Frankfurt

September 17, 1975

Persons Contacted

Mr. Wilhelm Stelter, Ministerialrat, DB

Mr. Kurt Bauermeister, Ministerialrat, DB

Mr. H. Dennert, Engineer, DB

Mr. Jurgen Stender, Engineer, DB

On September 17th, we visited the German Federal Railways in Frankfurt, Germany. Present were Mr. Stelter and several assistants.

The conversation centered for some time around a description of their electrically propelled, multiple unit train, experimental train 403. The characteristics are as follows:

Axle loading - 15 tonnes
Traction Motor - mounted on truck frame
Propulsion - thyristor controlled
Auxiliary power - static converter
Pantograph - static pressure 8 kg
Transformer coolant - mineral oil
Cooling air - obtained from underneath car
Braking - disc and dynamic (grids on roof)
Catenary height - 5,250 to 5,500 mm
Catenary voltage - 15 kv - 16 2/3 H2

The initial three train sets have control units at each end - one pantograph with two intermediate cars. Power is trainlined to traction motors on all axles. The train is operating in revenue service at a speed of 200 km/hr. The trains have experienced only one failure.

The cars are equipped with MAN trucks that have coil spring primary and air bag secondary.

Locomotive 103

This is a thyristor controlled locomotive limited to 160 km/hr due to braking distances and signaling system. The locomotive is capable of 200 km/hr. Below 160 km/hr, the engine crew consists of one man.

The 103 locomotive has AC traction motors equipped with commutators and brushes. The traction motors power the wheels by means of spring packs actuating spokes of the wheels. The locomotive has three axle trucks, weighs 116-tons. The weight per axle is, therefore, 19-tons. The Siemens cab signal provides a moving band on a speedometer which indicates allowable and actual speeds. The locomotive is equipped with dynamic and air brakes.

The Germans indicated approximately 30% of total track is electrified and movement on these tracks is approximately 85% of total traffic.

Outside of the office building were several of the newest passenger cars being operated by the Deutsche Bundesbahn. The sleeper car compartments were easily converted from singles to three high bunk beds. The equipment was very innovative and provided excellent space utilization.

That afternoon we rode a TEE train between Frankfurt and Munich powered by a 403 locomotive. The train included observation, diner and buffet/bar cars. The train had both first and second-class cars. The first-class car was equipped with 6 passenger compartments. The cars are modern and bright, equipped with large windows for sight-seeing.

3.3.2 Demonstration Test Ride on E-403 to Ausburg and Discussions in Munich

September 18, 1975

Persons Contacted

Mr. Hans Ebeling, Acting President, DB, Munich
Mr. Hans Hackstein, Vice President, DB, Munich
Mr. Wolters, Head, Electrical Engineering Department
Mr. Gert Ebeling, Interpreter

September 18, 1975, we rode a 403 train for a short distance from Munich to its first stop (approximately 20 miles). The equipment is truly well-made and of excellent construction. The engineman has a meter display indicating catenary current and braking current; and three meters for current to six motors. One stretch of track was provided with a control wire placed between the rails with a return wire on one of the rails. As far as we could learn, the failure rate on this equipment has been almost zero.

Later that morning, we visited the center of DB development in Munich. We talked with Mr. Bodens and several assistants. This center houses the electric, diesel, signaling, construction, and track engineering departments of DB. All design and development work is done here. The DB operates approximately 2500 electric locomotives. Of these locomotives, all but 30 are equipped with single-phase AC traction motors. The long term planning is to convert to three-phase motors. They are operating an experimental unit with static converters to synchronous condenser three-phase traction motors. The unit has operated some 20,000 km without fault.

According to these engineers, three train 403 sets have operated since 1972 with but one failure. The estimated cost at approximately 7 million marks. (Exchange rate = 2.45 marks to each dollar.) They also estimated cost of 103 locomotive at 3 million marks.

They indicated they felt tilt train mechanisms are too expensive. They have measured track force inputs by means of instrumented wheel sets.

The distances between substations on the German Federal Railroad can be as much as 40 to 80 km. This means a serious voltage drop and poor train performance at times. High current return loads cause some interference with 100 Hz signal system.

In the afternoon, we visited the DB Electric Locomotive works in Munich. The shop maintains 1100 electric-locomotives, some as old as 45 years, and 400 electrically powered passenger cars used in suburban service. The shop employs 1500 workers and 200 trainees.

Outside of the shop was a new series 110 electric-locomotive. There will be 70 built. The first locomotive received has been in service 6-months. The traction motors are AC powered.

The electric-locomotives are brought into the shop ever 4 years after accumulating 600 to 800,000 km. The trucks are changed out and all electrical and brake equipment refurbished. The AC traction motors are turned and the commutator slots undercut. The time in shop is 4 to 7 days. The traction motors are re-impregnated after 20 years.

The suburban cars are equipped with DC traction motors using thyristors for current control.

Locomotive 111, which was in the shop, is a 4-axle, 83-ton, 5000 hp locomotive capable of pulling a 650-ton train at 150 km/hr. The DB anticipates a minimum of 40 years service-life for each locomotive.

The wheels for the locomotive are 50-inches, and the spokes are driven by springs similar to the GGI locomotive. The traction motor weighs 3.6-tons, the wheels and axle 3.2-tons. The traction motor brushes last for approximately 100,000 km.

The locomotives are equipped with disc and dynamic brakes. The dynamic braking grids are located underneath the locomotive and used for heat in the winter.

3.3.3 Visit to Knorr Brake, Munich

September 19, 1975

Persons Contacted

Mr. Steven M. Brattain, American Consulate
Mr. Joachim Schultz-Naumarm, Board of Directors, Knorr
Mr. Gregory Gagarin, President, Knorr, U.S.
Mr. Peter Monagle, Engineer
Mr. Gerd Meier, Engineer, Knorr
Mr. Jim Phillips, Metroliner Truck Project Engineer, LTV
Mr. Lee Head, Metroliner Program Manager, LTV
Mr. Roland Raven, Chief of Engineering Design, LTV

On September 19, 1975, we visited the Knorr-Bremse plant in Munich. The morning was utilized to discuss the failure of the disc brake on the Metroliner car 850 LTV/SIG truck. Apparently this failure of the shrink-ring sleeves was due to excessive loading during initial testing, and higher impact loads than had been anticipated. It was generally agreed the failure of the sleeves that attach the disc to the ring shrunk within the wheel-hub was caused by g loadings on the sleeves that was in excess of loading used for design purposes. To provide for loading on the disc of approximately 60 g's, the present single-sleeve will be replaced by a double-sleeve.

The damage to the disc itself was caused by excessive heating during the truck test period. During this period, the pressure of the disc pads was approximately 40% too high. Braking test runs were made during this period from a top speed of 130 mph. Subsequently, the pressure on the Metroliner 850 disc brake was lowered to make the braking effort equal to tread braking on other Metroliner cars.

During the afternoon, a tour was made of the plant which produces diesel engines in addition to braking equipment. The research facilities contain testing equipment for various modifications to brake valves and related equipment. In addition, work is going on to provide active passenger car curve tilting by means of rubber air bags. The sensing equipment includes gyroscope and accelerometers. The plan calls for an axle-mounted compressor to pump air from one bag to the other, as required by the curve. The DB is interested in this work, but does not feel the benefits warrent the maintenance problems associated with the additional equipment.

3.4 Visit to ASEA in Vasteras

September 22, 1975

Persons Contacted

Mr. John Frostberg, Chief Director of Rolling Stock, Swedish State Railways

Mr. Ake Nilsson, Manager of Sales Department, ASEA

Mr. Tore Nordin, Manager Traction Department, ASEA

Mr. Bengt Gumdmark, Manager Transformer & Traction Department, ASEA

Mr. Erik Olson, Manager, Transport Systems Department, ASEA

On September 22, 1975, we visited the ASEA, Inc., facilities at Vasteras, Sweden. In the morning discussions were held with Department Managers who described recent developments in the areas of traction motors, transformers and high speed trains.

The latest design locomotive is the thyristor class Rc-2 and 3. The only difference between the class Rc-2 and Rc-3 is the maximum speed of 135 km/hr and 160 km/hr for the Rc-3 locomotive.

The locomotive is designed for an output of 4,900 hp, equipped with two axle trucks and weighs 80 tons. There are ASEA disc brakes on all wheels. The locomotive may or may not be equipped with dynamic brakes.

The main transformer and the converter are both oil cooled. Oil cooling of the semi-conductors has proven very successful. There has been no history of fire due to using mineral oil as a coolant.

Traction Motors

The traction motors are separately excited and the commutating flux is separated from the main flux in a special laminated circuit. This design results in a minimum of damping of the commutating flux, while a certain damping of the main flux is obtained. The commutating is extremely good with a brush wear of 30,000 to 120,000 miles per inch. One of the main pole shoes has a metering winding giving an output signal, the frequency of which is propostional to the motor speed and thus, acts as a speed transmitter. The motor has a three-point suspension in the bogie. The stator windings are insulated with class F, the armature winding with class F or H. The torsion shaft passes through the hollow shaft of the rotor. One end is connected to the rotor by a toothed coupling and the other end via a rubber coupling to the gear unit.

The load sharing between the traction motors is accomplished via the motor fields, which are automatically controlled so that the armature currents will be equally large.

After the armature converter becomes fully advanced, current control takes place through field weakening.

High Speed Train

Tests have been run on converted baggage cars up to a speed of 145 mph. One of the criteria for the train performance was that track forces would not exceed the forces generated by a locomotive at a speed of 80 mph. The cars used were self-propelled, electrified, thyristor controlled.

The cars are actively tilted in curves by means of air springs in the secondary suspension. Accelerometers activated the change in pressure between the two air springs. The signal produced in each car is integrated with a signal received from the lead car.

One car is provided with instrumentation and data recording equipment. This car is also equipped with an instrumented wheel set. The wheels are machined with a worn wheel profile.

Electrification

At present, 61% of the Swedish State Railways (SJ) is electrified with a B catenary system that carries 15 kv at 16 2/3 hz. Some 93% of the traffic is hauled by electric traction, the remainder is diesel-electric. The maximum speed for passenger trains is generally 130 km/hr on double-track and 100 km/hr on single-track.

The electrical equipment for the English APT is provided by ASEA.

In the afternoon we visited the plants producing traction motors and electronic control equipment. The traction motors receive heavy maintenance at 720,000 miles. Brushes last 100,000 miles.

A load measuring presducer is applied to the gear box. The presducer measures vibration due to overload and serves to reduce power to individual motors. The presducer consists of transformer coils 90 degrees out-of-phase mounted on metal back.

Train Trip

Later that day, we rode from Katrineholm to Stockholm in an Rc-3, 2-year old locomotive. Air is taken from the roof line to cool the traction motors and other electrical equipment. The engineman is on the left. One air gage only is used and that indicates brake pipe pressure. The electrical control equipment provides speed maintaining. Speed control is obtained by operation of a TM current regulating reostat. No train control or cab signal system is provided. The buffing strength of the locomotive is 600 to 700,000 lbs. Top speed was 135 km.

Outside of Stockholm we transferred to ride new thyristor controlled suburban service cars. These cars were very smooth and quiet, but again without train control.

3.5 Switzerland

3.5.1 Visit to SIG Facilities in Neuhausen Rheinfall

September 23, 1975

Persons Contacted

Mr. Jean-Paul Geiser, Vice President Railway Division, SIG
Mr. Bernhard H. Huber, Chief Project Engineer, Railway Division, SIG
Mr. E. H. Rubli, Manager of Export Sales, SIG
Mr. Paul A. Reithaar, Manager U.S. Sales, SIG
Mr. Hans J. Ulrich, Chief of Hydraulics Division, SIG
Mr. Franz Wicki, Project Engineer, SIG
Mr. Jim Phillips, Metroliner Truck Project Engineer, LTV
Mr. Roland Raven, Chief of Engineering Design, LTV

On September 23, 1975, we visited the SIG plant at Neuhausen on Rheinfall. We inspected the manufacturing facilities and found that there was little production work underway. There were trucks in final stages of fabrication to be installed under cars being produced by another Swiss car builder. SIG recently completed production of 50 new passenger cars for the Swiss Federal Railway. Four of these cars are considered prototype and equipped with a tilting mechanism. The truck and tilting equipment were designed and fabricated by SIG.

The new cars were placed in service in June and the prototype cars have been undergoing testing. The locomotive that pulls the prototype train is a standard four-axle, 80-ton electric locomotive <u>without</u> tilting mechanism. Tests were therefore made to determine whether the track forces generated by increased speed through curves would be excessive. It was determined that the forces were not excessive and further testing of the mechanism is now being completed.

The new car weight is 33-tons, and the truck was designed for a maximum speed of 140 km/hr. The banking system means:

- Increased operating speed on trucks with numerous curves.
- Considerable improvement in riding comfort.

The SIG banking systems features:

- Optimum comfort due to quick signal response.
- Noise and jerk-free banking motions.
- Train composition flexibility.
- Relatively small investment compared with expensive track changes.
- Modest installation investment cost.
- Full operating safety in case of system failure.
- Mechanical interlocking of carbody to truck in case the banking system is not used.

The signal system is produced by Honeywell and consists of a lateral acceleration sensor in the locomotive or proceeding car which is integrated with a centrifugal force signal to produce a control signal to a hydraulic plug in unit. This unit supplies pressure to hydraulic actuators on each truck. The maximum angle of tilting is 6 degrees. The signal response time to entering curve is approximately 0.1 second.

The speed increase on curves varies but becomes effective from 100 km per hour on curves over 400 meters in radius. Between 500 and 600 meters the speed increase is on the order of 25 km per hour.

The fail-safe mechanism includes providing an indication to the engineman that one of the tilting arrangements has failed and that normal speed must be run through curves. All car mechanisms will automatically lock in neutral condition.

On September 24th we went from Neuhausen to Winterthur to Bern. The trip between Winterthur and Bern was in a first class electric powered train. We left Bern at approximately 11 a.m., and made a round trip test of approximately 120 miles. The track was very curvy and the train entered and left the curves very smoothly. The banking system was cut out in one car and the change in the ride was dramatic.

A meeting was held with SIG representatives on September 25th to discuss whether or not the prototypes would be available for testing in the United States. Mr. Jean-Paul Geiser indicated that he would be able to arrange with the Swiss Federal Railway for such a test if it became desirable.

LTV has an agreement with SIG to be their representative in the U.S. A discussion was held concerning the purchase of additional SIG/LTV trucks for use under Metroliner cars.

3.6 Visit to Fiat Turin Facility in Turin, Italy

September 26, 1975

Persons Contacted

Mr. William H. Skok, U.S. Vice Consul
Dr. Ing. Renato Piccoli, Senior Official, Fiat Rail Division
Mr. Oreste Lantanera, Assistant to Dr. Piccoli

On September 26, 1975, we met with Mr. Piccoli of Fiat and his assistants. Mr. Piccoli is in charge of Railroad Equipment production for Fiat. Fiat is the principle producer of passenger cars and locomotives in Italy.

Mr. Piccoli expressed a great deal of interest in providing equipment for US consideration. Fiat produces both diesel and electric locomotives and has a four-car, self-propelled, high-speed, tilt, electrically propelled train under test. Two of these cars were at the Milano plant and two at Bologna for exhibition at the International Conference.

Dr. Piccoli stated that he felt that a static inverter locomotive would be in production within five to six years. This will mean the introduction of brushless AC traction motors.

The majority of the Italian State Railways is provided with a 3,000-volt DC traction system.

In addition to building a tilt train for the Italian Railways, a train is being built for the Spanish State Railways. Its top design speed is 155 mph. The Italian standard for the negotiation of curves allows passengers to be subjected to a centrifugal acceleration of 0.8 m/s^2 Thus, on a curve of 14,80 foot radius, the maximum speed would be 62 mph. With so-called variable inclination, the curve can be taken at a speed of 84 mph, keeping the lateral acceleration to the permitted level of 0.8 m/s^2.In order to reduce the strain on the track, the train was kept as light as possible.

The train set consists of four cars with two streamlined cabs at each end. The basic four car unit can be varied by adding two-car elements to produce a 6, 8, and 10-car train. Each car has two bogies and four traction motors and two auxiliaries. Each traction motor is intended to run at 1,500-volts; thus, there are two couples of motors in series which are commutated in parallel-series. These self-ventilated motors are equipped for series and independent excitation. The traction motors are used for dynamic braking.

The regulation of speed is automatic so that the train maintains the selection of speed made by the engineman.

The braking consists of two disc brakes per car, electrodynamic high-speed braking is complemented by use of an electromagnetic shoe devise acting directly on the rail.

The tilting of the body is achieved hydraulically through two cylinders per truck which act between the swinging member and the carbody. The flow in the cylinders is regulated from zero to the level corresponding to the maximum rotation velocity of the body through specially controlled valves. The main difficulty with tilting is achieving the car inclination quickly enough. Since a 328 foot stretch at 112 mph is covered in two seconds, it is clear that the time available is extremely limited. In order to provide the proper signal to the servo-assisted devises, both lateral acclecrometers and gyroscopes are used on each car. The maximum degree of tilt is 10 degrees.

The afternoon of September 26, 1975, we visited the Fiat production plant for railway equipment near Milano. Fiat completely manufactures diesel locomotives and passenger cars, including all necessary electrical equipment.

On October 2, 1975, we made a trip between Bologna and Chuisi on two of the new Fiat tilt cars. The cars had good acceleration and ran very smoothly on the tangent track. The impression was that the first car had a decided, sudden tilting movement into and out of curves. The second car was much smoother and more comfortable to ride. This is because the sensor for the second car was located in the lead car, providing a smooth transition from the non-tilt position to the tilt position of the car. The lead car, however, does not have a lead sensor and, therefore, experiences a sudden transition.

That same day we rode new Italian Railway passenger cars over the new 'Directissima," Rome-Florence Line. This is a brand new two-track line that parallels an existing two-track line and, thus, provides a four-track railroad between the two points. It is intended to provide high-speed service up to 150 mph on the new line.

The new line will be electrified at 3,000 volts DC. The rectifier sub-stations will be fed by two 130,000 volt, three-phase distribution lines. The sub-stations are fed alternatively, and an outage of one of the lines would not cause a discontinuity of operations. The sub-stations are spaced approximately 16 Km apart.

The contact system is made up of two grooved contact wires directly hanging from a single catenary by means of droppers. Each wire has a 150 mm^2 section and the catenary is a cadmium-copper cable with a 160 mm^2 section equivalent to a 140 mm^2 copper section. The wires and catenary mechanical tensions are automatically regulated by means of cast-iron weights attached to a pulley system. A portal structure was designed to hold the uncovered line. The base of the portal is hinged to reduce propagation of ground vibrations to the structure.

The signaling system is designed for a train stopping distance of 5400 m. All track circuits are fed at 50 hz AC. Four coding rates are used at this frequency and, in addition, in order to provide continuous cab signals at the higher speeds; a second carrier frequency of 178 hz is imposed on the track. The track circuits are equipped with impedance bonds with shortest circuit lengths of 1350 m. The automatic block sections have a length of 5.5-6 km., each one providing a complete braking space over four track circuits. The spacing between the high-speed trains will be not less than 10 Km. The automatic blocks are signaled for operation in either direction. Eight speed signals will be shown in the cab in addition to stop.

The CTC and the train describer, with scheduling, will be managed by several data processing devises that, for reasons of reliability and of working continuity, will be duplicated. The visualization of the traffic condition will be given by alpha-numerical videos in black and white.

The telecommunications system provides circuits for:

a. Connecting the electric sub-stations to each other and to wayside operator rooms;

b. Selective circuits for traffic controller.

c. Automatic circuit for connecting electric sub-stations to the general automatic FS network.

d. Service circuits for the maintenance of the safety and block devices.

e. Circuits for data transmission; and

f. Circuits for train to wayside and high frequency circuits for long distance connections.

During the trip on the new Direttissima, Rome-Florence line, we stopped to inspect the construction of new track. A concrete slab approximately 10 inches thick, is poured on the soil base the complete width of the double track. Attachments for the catenary poles are made to this slab. Atop the slab is placed approximately 20 inches of ballast. Concrete tie and rail panels approximately 40-feet in length are placed on the ballast and the rails flash-butt welded. The track is subsequently leveled, lined, and tamped making use of a four-sleeper tamper with a dynamic stabilizer attachment.

The Direttissima Rome-Florence line will have no curves with a radius less than 3000 m. There are 53 viaducts and 30 tunnels. It will be possible to operate trains at speeds up to 250 Km/hr on this line.

TRIP REPORT

FEDERAL RAILROAD ADMINISTRATION
&
NATIONAL RAILROAD PASSENGER CORPORATION

EUROPEAN VISIT
FOR
TECHNOLOGY EXCHANGE CONFERENCES
IN
GERMANY, SWITZERLAND, AND FRANCE

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

January 14 to 25, 1977

TRIP REPORT
M. Clifford Gannett

Friday, January 14, 1977, Cologne

I arrived in Cologne, January 14, 1977, and spent the afternoon at the Baerman Laboratory. Mr. Baerman and his assistants have worked on a number of eddy-current brake designs. In addition to the eddy-current brake that reacts on the rail, Mr. Baerman has arranged eddy-current brakes that will react on the wheel tread or on a reaction plate attached to the axle similar to a disc brake.

We went through calculations which indicate the power input to stop a car such as a Metroliner from a speed of 150 mph would be approximately 175 kW. Mr Baerman has designed an axle generator that can develop approximately 140 kW.

The German Federal Railway has purchased an experimental unit to be applied to a freight car operating in a mountain route. The Swiss Federal Railroad has also purchased a unit for experimental use.

The unit that operates on the wheel tread has been designed for a Minden Deusch passenger car truck. We will follow the progress of the German and Swiss experiments and ask the US representative, Westcode, to provide a budgetary cost estimate for an axle generator and eddy-current brake that can be applied to a car such as the T-7.

Monday, January 17, 1977

Monday morning introductions and a welcoming speech was made by Dr. Thoma of the German Federal Railway and a response was made by Dr. Spanton.

Dr. Spanton, Ned Ahmed, and I gave a report on the status of DOT/FRA research activities that was in considerable detail. Messrs. Frerk and Spöhrer gave a report of German activities in very general terms.

On Monday afternoon, we met with Dr. Frenzel concerning the sub-agreement entitled "Optimal Interconnections." Prior to the meeting, Mr. Kuhla indicated we were to discuss policy matters, but that program details would be discussed later in the week in Munich. During the meeting, Dr. Frenzel indicated that he was faced with severe budget problems and, consequently, was doubtful that he could contribute significant funding to the program. We, in turn, made the same statement.

Later in the week, Doctors Wormley and Cooperider had discussions with Messrs. Spöhrer, Kuhla and a group of engineers employed by Mr. Spöhrer, who are developing models reflecting the dynamics of vehicle wheel/rail interface. It is apparent that Mr. Spöhrer would like to continue the program and does have manpower available to make a contribution. Our contact for this work has thus shifted from Kuhla/Frenzel to Kuhla/Spöhrer.

Tuesday, January 18, 1977, Bonn, Mannheim

Tuesday morning we traveled by train between Bonn and Mannheim. During the trip we had the opportunity to ride the E-103 locomotive. The locomotive has a combination of tap changes and thyristor control. The top speed presently permitted on the German Railways is 160 Km/hr. This locomotive is designed for 200 Km/hr and has been tested at that speed. The locomotive is rated at 8,000 kW and weighs 114 metric tons. The locomotive has two three-axle trucks and, hence, the load is 19 tons per axle.

After arriving in Mannheim, we went to the Deutsche Bundesbahn engine house to inspect the diesel-electric locomotive DE-2500. This locomotive has a line connutating inverter that provides variable voltage, variable frequency to three-phase AC traction motors. The locomotive was built by Henschell and has Brown Bavaria electrical equipment. This locomotive has been under development since 1966. The Swiss Federal Railway has ordered 6 heavy duty diesel-electrics with three-phase traction motors. The DB has three such units under test.

To demonstrate the tractive characteristics of the locomotive, it was run against an end of the track collision post and permitted to run with throttle open. The asynchronous motors will not overheat and destroy themselves as DC motors would do.

We next visited a large marshalling yard outside Mannheim. This yard will classify between 6,000 and 8,000 cars in each direction daily. We were particularily interested in the cable arrangement used to bunch cars after they passed through the hydraulic retarders. A cable is used to move a steel bar that pushes behind the wheel to close the gap between cars.

We then visited the construction site for the new Mannheim-Stuttgart line. This line will be 105 Km long and is being built to accommodate train speeds of 300 Km/hr. It is planned to operate at 200 Km/hr when the line is opened and later the speed will be increased to 250 Km/hr. The line will be double tracked and used for passenger service only. The freight traffic will use the present two tracks. The present tracks are moving an average of 360 trains per day. The new track design parameters are as follows:

Curve radius, normal	7,000 m
Vertical curve radius	-5,300 m
Track centers	4,700 mm
Max elevation	150 mm
Rail weight	60 Kg/m
Rail inclination	1 in 40
Tie concrete	B 70 W
Tie spacing	600 mm
Ballast depth	30 cm
Ballast shoulder width	50 cm
Substructure elasticity modulus	800 Kg/cm^2

Films were shown concerning environmental protection activities of the DB and a film indicating the progress of the Roller Rig being installed at Munich University. The rig will be ready for check out November of this year. Tests on single wheel sets will be conducted in 1978 and full truck tests performed in 1979. The power station supplying the RDL will provide 10 mega watts of power at 16 2/3 hrs. The DB plans a staff of 18-20 people at the RDL.

A discussion of modeling wheel/rail forces was next on the agenda. The DB has developed a linear model with some twenty degrees of freedom. They have developed a model for tangent track operation, but not for curves.
Dr. Cooperider indicated that the Germans have not been as active in the field of suspension modeling as the United States.

The next subject discussed concerned electrification in the United States and I gave a review of the Northeast Corridor project including electrification at the Pueblo Transportation Test Center. I also gave a review of the equipment evaluation program presently underway.

The Germans asked for a discussion of the GM 10 electric locomotive, but we were unable to furnish any specific performance data. This item was not listed as an area of German interest prior to the meeting. We indicated we would pass along any information that EMD was agreeable to supplying.

In the afternoon, Mr. Bauer presented a paper on "Development of Mathematical Models for Overhead Contact Systems." A copy of this paper is attached.[1] During questioning, Mr. Bauer indicated that the light steel pole, cable and rod arrangement they use for double track is adequate for speeds to 250 Km/hr. The catenary is under constant tension and is almost entirely of uniform height.

A paper[2] was next presented by Mr. Guthlein concerning high-speed pantographs. The latest design that they are using is called SBS 65 and is produced by Siemens. This is a two-phase pantograph. The pan to which the carbon strips are soldered has a torsion element with rubber springs attaching it to the single area pantograph. Minor variations in height are compensated for by pan springs. This pantograph has been tested to a speed of 250 Km/hr (150 mph). Attached is a copy of Mr. Guthlein's paper.

Mr. Guthlein also presented the next paper[3] concerned with improving the power factor of electric locomotives with thyristor phase angle control. In order to improve the power factor and reduce harmonics, the Germans have developed an extinguishable, unsymmetrical bridge they call (LUB). The thyristors are extinguished by means of extinguishing thyristors (forced commutation). The charging energy is obtained from capacitors. The German locomotive E181-2 is equipped with two capacitor circuits. After two years experience, the Germans are satisfied they have improved power factor from 0.82 to 0.95. I have attached a copy of this paper.

Wednesday, January 19, 1977, Munich

Wednesday, after the sessions with the German representatives were completed, Messrs. Beuimister, Wolters, Schmidt, and I visited the Munich terminal shop of the DB and made an inspection of the ET-403 passenger train equipment.

Attached[4] is a listing of the technical details of the equipment. There are several features that I noted as being positive or negative and have listed them below:

Positive

1. Lightweight - The total train weight is 235 tons, an average of 14.6 tons per axle. This low weight was achieved by making the train of an aluminum alloy with a monoque structure and with a buff strength of 200 tons.
2. High Acceleration Rate - The acceleration rate is 0.6 m/sec^2 (mph/s). This is accomplished by powering all 16 axles with a total short time rating of 6,000 kW.
3. Non-Articulated Cars - Each car has two - two axle trucks.
4. Automatic Couplers - The cars have atuomatic coupling of the cars, electrical trainline wires and air brake piping. Also coupled, but not entirely automatic is the power line which is trainlined on the roof from the rear car. The only pantograph raised is on the rear car.
5. Auxiliary power supply - An auxiliary winding of the main transformer supplies single phase current for heating and air-conditioning. A 15 kW inverter supplies three-phase current for fans, etc.
6. Air Resistance - The front end is shaped for a minimum of air resistance based on wind tunnel testing that was conducted to determine the best shape for the front end of locomotives.

Negative:

1. The interiors of the cars have quite a bit of unused space. The interiors should be rearranged.
2. Due to the fact the Germans use low level platforms, steps must be provided. The steps have to be kept away from the truck envelope and the doors are quite far from the ends of the cars.
3. The solid state electronic equipment is air cooled. The air intakes are on the sides of the car. The Germans have not experienced difficulty during snowy weather. The only plausible explanation is that the grill work has been shaped to give a spin effect to the air and, thus, drop out dirt, etc. The filters are simple fiber filters that are changed every month.
4. The Germans feel that when the speed is increased to 200 Km/hr and over the axle loading should be reduced to 18 tons. In addition to using lightweight material for the carbody, they have narrowed the body width to 9'2".

As indicated on the attached listing of technical items, the cars are quite similar to Metroliners in that each car is equipped with a main transformer, smoothing reactor and 4 DC traction motors. The Germans do, however, use a secondary winding for excitation of the traction motor fields.

Mr. Wolters indicated that, if they go to production of high-speed trains, they would in all probability provide powered axles only at each end and use a fixed consist train.

The ET-403 trainsets are equipped with continuous automatic train running control (LZB) developed by Siemans. This equipment is described in an attachment.[5]

The public response to the ET-403 trains has been excellent. A 10 percent premium fare is charged and the load factor has been good. The trainsets average approximately 900 miles per day.

Thursday, January 20, 1977, Nürnberg

On Thursday morning, a trip was made to Nurenburg on the ET-403 train. The train accelerated and decelerated very smoothly and rode very well on welded track. On some sections of jointed rail the ride was only fair.

The (LZB) train control feature is very effective indicating continuously to the engineman the distance to the next restrictive signal. One of the two wires of the (LZB) systems is placed between the rails and the other is attached to one of the rails. A loop is formed every seven miles of track. The present development aims at centralizing equipment concerning the line. By the use of freely programmable process computers, it will be possible to centralize larger areas in so-called LZB computer centers.

At present, the German Federal Railway has equipped 260 Km and about 190 vehicles with LZB at a cost of approximately 70 million marks. A paper titled "Continuous Automatic Train Running Control" is attached.

Thursday afternoon a presentation was made on the use of a measuring car for quality control of the track. The Germans feel that for speeds over 120 Km/hr (72 mph) the practice of determining track geometry tolerances is not suitable for determining the admissibility of a given running speed. They use a measuring car traveling in a scheduled, revenue, high-speed consist to measure lateral accelerations and force at the axle bearing. Limit values have been established for tripping print out equipment and for flagging locations that require either track maintenance or speed restrictions. We will attempt to provide such equipment on our T-7 test car. A paper concerning this subject presented by Mr. Weigend is attached.[6]

Mr. Oberweiler next presented a paper[7] concerning the German efforts to develop a high-speed track geometry car. Efforts are under way to develop a non-contract high-speed car. It is planned that gauge measurements would be made by an optical-electrical procedure. Other measurements will be made by a sliding non-contact air-cushion-sensor. For vertical reference, a gyroscopic system will be provided. It is anticipated the geometry vehicle will become operational in 1981, and that the acceleration measuring car and track geometry cars will be run together.

After completion of the technical presentations Thursday afternoon, approximately three hours were devoted to making a preliminary listing of subjects that are of further interest to either the German Federal Railway or to FRA.

Friday, January 21, 1977, Munich

Friday morning a visit was made to the Institute for Landroutes of the "Technische Universitat" of Munich. Dr. Eisenmann is the Professor who directs the testing of railway materials. There were a number of tests underway of concrete ties and fasteners. In most cases they were simulating a wheel loading divided into a vertical component of 7.5 tons and a lateral component of 4.6 tons. They were doing both static and fatigue testing of ties and fastener components. Tests were also being made of field thermit welding of rail. They were also testing elastic rubber mats that are used for noise insulators in tunnels and subways. The mats are made from recycled tires and have proven very successful in the Munich Metro tunnels.

The newest concrete tie they are building is designated B-75. It is 380 Kilopons in weight and 2.8 meters long.

Dr. Eisenmann indicated tests have been carried on in the field to determine the lateral force needed to displace laterally a tie embedded in ballast. He indicated the critical lateral force level is dependent upon track panel geometry and weight of crossties. He indicated that the lateral force limitation of wooden ties is 45 lbs. per inch and that the limit for contrete ties would be 80 lbs. per inch. Laboratory experiments have been carried on with a 10-meter panel on rollers to test the rigidity of the panel under various lateral loads.

Dr. Biermann spent some time discussing the effects of the rail lifting wave. A paper is attached that explains Dr. Eisenmann's theories. A lifting wave preceeds the locomotive, also appears between bogies and between vehicles. The lifting wave results in a reduction in lateral stability of the track. Increasing the weight of the track panel serves to attenuate the pulse-like impacts of the sleepers on the ballast experienced at high speed.

Saturday, January 22, 1977, Zurich

On Saturday, January 22 Messrs. Spanton, Schmidt and Robert Clark of Northrop Corporation and I traveled on a locomotive of the Swiss Federal Railroad produced by the Swiss Locomotive and Machine Works from Zurich to Bellinzona, Switzerland. The locomotive is called Re$^{6}/6$ and is a BoBoBo design. It is reputed by the Swiss to be the world's most powerful locomotive. The Swiss railroads are powered by 16 2/3 Hz 15 kV current similar to the German traction system. The electric locomotives are powered by AC commutating traction motors. Control is by means of transformer tap changers. The Swiss experimented with a thyristor controlled locomotive and found the electromagnetic interference produced by the locomotive had a detrimental effect on their signaling system.

Accompanying us on this trip were Dr. Loosli and Mr. Erzinger of SLM and Mr. Peter Eggspichler, Assistant Chief Mechanical Engineer of the Swiss Federal Railroad. We rode the locomotive from Zurich to Erstfeld and there transferred to another R/6 locomotive hauling a freight train on to Bellinzona. The passenger train had a trailing tonnage of 530 tons. The trip was through the Gotthard pass of the Swiss Alps and, hence, the trains experienced very steep grades (up to 2.8 percent) and sharp curves.

Sunday, January 23, 1977, Pontresina

On Sunday we visited Pontresina, Switzerland, and inspected an aluminum truck developed by Alusuisse. The trucks are under a tank car owned by the RhB Railway. We were accompanied on the trip by Mr. Zehnder of Alusuisse. The trucks are designed to permit radial movement of the wheelsets in curves and have given satisfactory service for several years.

Monday, January 24, 1977, Neuhausen

Monday Messrs. Clark, Spanton, and I visited the Alusuisse technical center at Neuhausen. This center does stress analysis work on new aluminum extrusions and carries on research to improve welding techniques and procedures.

We next visited the SIG car building plant in Neuhausen. We had a discussion with Messrs. Reithaar, Wicki, and Huber. Mr. Huber showed us slides of the mechanism used for tilting standard car type 111 of the Swiss Federal Railways. One train consist of thirteen cars is equipped with tilting mechanisms although the mechanisms are not presently operational. A series of tests were completed and the SFR agreed the trains could operate in curves at higher speeds than conventional trains. The criteria used was that the track forces generated by the locomotive would not exceed those forces generated by other, heavier locomotives, the lateral acceleration on passengers would not exceed 0.85 m/sec^2 and the L/V ratio would not exceed 1.2.

The hydraulic actuators for the tilting equipment on each truck are actuated by a control signal from an electronic control unit. The control unit receives a signal from accelerometers on the car and the preceeding car or locomotive. The fact a signal is received from a preceeding car makes the transition into and out of curves very smooth.

The control equipment is so designed that the locomotive engineman will receive an indication if any of the tilt mechanisms are not functioning. In that case, the car will be locked in a non-tilting arrangement and the engineman will operate the train at normal speeds through curves.

The SFR is presently making a marketing study to determine whether to increase the speed of one revenue consist with an appropriate advertising campaign. The tilting mechanism increases the initial cost of the car approximately 20 percent. SIG prefers to sell new cars and, hence, is not actively pushing the sale of the tilting mechanism. SIG produces the truck mechanism and hydraulic plug in pump unit. The control unit is produced by Honeywell.

Fifty of the new type 111 cars were produced by SIG. All of the trucks are designed so that by replacing the truck bolster, the cars can be converted to tilt cars.

That afternoon we visited the plant of the Swiss Locomotive and Machine Works in Winterthur. Messrs. Erzinger and Loosli discussed the advantages of electrified train operations. Mr. Erzinger estimated the maintenance cost per mile of a 3,600 hp locomotive at 27.5 cents and the equivalent cost of a 11,000 horsepower electric locomotive at 13.5 cents. The availability of various classes of electric locomotives varied between 90 and 94 percent.

The Re 6/6 locomotive was originally equipped with an articulated body. Later, the locomotive was designed to have a solid body. Research carried on by SLM made it evident that interconnected trucks provided a desirable steering effect on curves 700 meter or less in radius.

We made a tour through the plant. The plant is not large, but has adequate machine capability for the limited production required for Swiss locomotives.

The Swiss feel the BoBoBo arrangement is ideal for providing high horsepower on steep grades and yet inputs a minimum of static and dynamic guiding force into the rails.

Tuesday, January 25, 1977, Belfort

On Tuesday, January 25, I visited the Alsthrom shops at Belfort, France. One shop is concerned with the construction of diesel-electric and electric locomotives and is called "Groupe Des Fabrications De Traction." Mr. Michel Penicaud, the Deputy Director, gave me a tour of the shop. The shop employs approximately 1,500 people and produces 200 locomotives a year. In addition, passenger cars are built at this shop when orders for locomotives are low. The TGV trains will be built in this shop.

The shop completely fabricates the body and trucks and wires in components. Some of the components are furnished by Alsthrom from an electrical shop located at Tarbes and another by MTE-Francorail and other suppliers.

We discussed the characteristics of the locomotive delivered to Amtrak for testing. There have been 78 of this type of locomotive built since 1966, 74 1,500 V dc and 4 multi-current. The locomotive is CoCo and weighs 132 metric tons. The locomotive has a continuous rating of 8,000 hp (5,900 kW) and is geared for a maximum speed of 137 mph (230 Km/hr). During testing of pantographs in high-speed service, it was operated at 280 Km/hr.

The locomotive operates in revenue passenger service at a maximum speed of 200 Km/hr and averages approximately 40,000 Km each month. Due to the isolation of the mono-traction motor from track disturbances, the traction motors average approximately 800,000 Km between major overhauls.

The particular locomotive furnished Amtrak was built in June 1974. Although this locomotive has been in production for 10 years, Mr. Pencaud indicated that no major design changes were planned. The locomotive furnished Amtrak was provided an automatic coupler, horn, bell, improved lights, and additional material added to the side sills for added compression strength. Mr. Pericaud indicated they test to 200 metric tons, but allow only a very small deflection. The original bogies were fatigue tested and each bogie is static tested prior to leaving the shop.

We made a detailed inspection of all phases of the locomotive fabrication, assembly, and testing. I was very much impressed with the quality of the machinery, the methods, and the workmanship. The locomotive is fabricated from mild steel. The main strength members are the side sills. The front end is built very strongly and affords the engineman adequate protection. Cross members are placed between the side sills for floor support and for hanging equipment below the floor level. Side posts are placed on the sills for roof support and for securing side sheets. A large portion of each side is equipped with air intake grills that cause the air to reverse direction and filters a large portion of the dirt carried by the air.

ATTACHMENT 1

Dipl.-Ing. Bauer

Bundesbahn-Zentralamt München
Dez.25

Development of mathematical models for overhead contact systems

Gentlemen,

Because of their design overhead contact systems are structures with extreme capabilities of oscillation. They mainly consist of contact wire and catenary which are jointed by a dropper. Normally they are subjected to high tensile stresses and the spacing between their supports is about 60 to 80 meters.

Viewed from a physical aspect, this system has repeatedly been described as a system of two strings which are coupled in many different places and which are heavy in weight and rigidly fixed.

This arrangement is characterized by the following order of frequencies:

- natural frequency of overhead contact system	approx.	1 Hz
- excitation frequency due to mast spacing	"	0-2 Hz
- excitation frequency due to dropper spacing	"	0-15 Hz
- maximum deflection of contact wire	"	15 cm

The indicated values apply only to the fundamental wave. The numerous couplings and anchorings result in a plurality of harmonics and beats. Furthermore, the overhead contact system oscillates already by the influence of winds.

For this complex energy transmission system it is necessary to find optimum ways for the interaction of contact wire and pantograph. This system could be designated optimal if the following requirements were met:

- if the force occurring between contact wire and pantograph remains as constant as possible preventing voltage interruptions
- if vertical movements of the system remain insignificant preventing damage.

The search for an optimum interaction is as old as the system itself but under the aspects of higher speeds and of contact wire wear it has been activated during the past years.

First of all I should like to indicate the influences which have the greatest effect on the oscillatory behavior. These are:

<u>In the case of the overhead contact system</u>

- the weight of the contact wire
- the weight of the catenary
- the tension in the contact wire
- the tension in the catenary
- the spacing of supports
- the spacing of droppers ~~and mast~~
- the weight of the stich wire
- the tension in the stich wire
- the length of the stich wire
- the radii of curves
- singular points, i.e. points with abruptly changing elasticity (for example, tensioning sections, disconnecting points, fixed points, sections of subsidence) or points with abruptly changing mass distribution (for example, registration arms, heavy clamps, disconnectors).

<u>In the case of the pantograph</u>

- the statical and aero-dynamical contact pressure
- the weight of all components (frame and pan)
- the elasticity of all components
- the damping of all components

<u>In the case of the tractive unit</u>

- the oscillatory behavior of car body and bogies

<u>In the case of the permanent way</u>

- the changes in elasticity

All these parameters may influence the oscillatory behavior in a significant manner. There are further factors, as for example, the stiffness of contact wires, but they are to be neglected in this discussion.

For the optimization of an overhead contact system it would be prerequisite to know the effects of the individual parameters. For the purpose of a scientific investigation the following <u>minimum program</u> could be proposed:

contact wire	2 different weights (cross sections)
"	2 different tensions
catenary	2 different weights (cross sections)
"	2 different tensions
mast spacing	6 different lengths
dropper spacing	4 different lengths
stich wire	2 different weights (cross sections)
"	3 different tensions
"	2 different lengths

In order to detect the influence of these few basic parameters it would be necessary to examine 4608 individual cases. For each individual case a complete tensioning length would have to be selected because experiences made evident that the changing of parameters is not advisable if the result is to be ~~unambiguous.~~ clear

Since, for the present, we are confined to the experimental approach it would require a test line with a length of approx. 5500 km. A reduction of the program length would mean the successive provision of different constructional stages and would furthermore mean that the original condition would have to be restored each time a new pantograph is to be tested.

It is to be seen at first glance that the realization of this idea is impossible, if not to say utopian. Nevertheless, these ideas had to be mentioned here in order to demonstrate the impossibility of a systematic optimization by way of experiments.

Besides, these thoughts show very clearly the complexity of the situation and they furthermore will have a significant influence on the computer program.

What further possibilities are available?

BR deduced model laws for overhead contact systems. According to this it should be possible to run with a model speed amounting to half of the actual speed if all longitudinal dimensions of the overhead contact system were also reduced to half value. It is immediately apparent that this method is also unsuitable for the present case. Furthermore, it also has other disadvantages.

Under the given circumstances it seems an obvious conclusion to search for a suitable mathematical model. Approaches in this direction are very old and have been tried with more or less high expenditures. First approaches can be traced back to Nibler. In 1967 Ebeling published a comprehensive description of the situation at that time.

However, all these models covered only partial aspects. Because of the complexity mentioned before it was not possible to give an extensive representation. The break-through in this method was not possible until electronic computer installations were developed.

Several years ago, the International Office for Research and Experiments (ORE) at Utrecht instituted an experts committee dealing with questions of high-power overhead contact systems for high speeds. DB is also participating in this work. Within the scope of this task a computer program for overhead contact systems and pantographs was elaborated in 1974.

Within the bounds of a high-power high-speed project sponsored by the German Federl Government, Fischer, AEG, developed a similar program in 1975.

Both methods solve the problem by means of numerical simulation in a large computer. In these cases the mathematical model is described by the following most important elements:

- all wires are represented as tensioned strings
- their weights are subdivided into discrete and almost equally spaced points.
- the length of these spacings is freely eligible. However, every mass concentration, as for example, registrations arms, dropper clamps etc. has to be considered ~~detected.~~ Smaller values of this mass concentration provide more accurate results but unfortunately lead to a square increase of computer time. The computer very soon reaches its limits.
- the pantograph exerts a variable vertical force along ~~on~~ the contact wire. ~~in longitudinal direction.~~
- the variable forces occurring at pantograph and overhead contact system are specified by the equation of movement concerned.
- in suitably short intervals of time the computer calculates ~~computes~~ the locations of all mass points in the system in such a way that balance is assured.

An essential advantage of this model is the fact that all important influences can be detected simultaneously. These are among others:

- weights and masses of cables and wires
- tensions " " " "
- flexural stiffness " " " "
- damping " " " "
- influence of the stich wire
- influence of droppers; the method of Fischer (AEG) also detects slack droppers
- the pantograph as damped system oscillating in several stages

What values can be issued by the computer?

From each simulation the following data can be issued:

- path of the pantograph along the contact wire
- in the case of the Fischer-method also the reduced path for the base of the pan on the frame
- the pattern of contact forces occurring between contact wire and pantograph
- in the case of the Fischer-method also the contact force reduced to the point between pan and frame.

The reduced values are of importance because they are the only values which can be measured during testing and compared to the values of the computer program. The immediate contact point between contact wire and contact strip can not be measured.

What statements can be made concerning application?

Both programs of ORE and AEG were completed only recently. They are presently being compared to results of high speed tests.

The ORE method supplies useful values as far as it concerns complete departures from the previous system, that is, if mass, tension or elasticity differ considerably from previous values. However, for a real optimization the expenditure of computation is too high.

The Fischer method has not been tested yet but if an optimization is to be achieved this method also requires very high expenditures.

It will definitely not be possible to optimize the afore-mentioned 4608 cases. One single case with a tensioning length of 1200 meters would already require a computer time of 3,5 hours. It would therefore take 1,8 years to test the entire system. This is to demonstrate the limitations existing also in this method.

Therfore, both ORE and Messrs. AEG search for new possibilities of solving the problem. These solutions are to provide the following:

- considerably reduce computer time
- make possible an analytical representation of mathematical functions.

Conclusions concerning the system can be drawn more easily if an equation is available.

Gentlemen, I have tried to verbally describe to you the extremely complex mathematical model for overhead contact systems and pantographs and I should be very happy if these elucidations were informative to you.

ATTACHMENT 2

Dipl.-Ing. Güthlein

Deutsche Bundesbahn
Bundesbahn-Zentralamt München
21

Design of a pantograph for high speeds

Gentlemen,

One of the most important problems concerning energy supply to high-speed tractive units is the correct design of energy supply equipment, namely the design of pantograph and overhead contact system. The physical conditions of the interaction of pantograph and overhead contact system are similar to those between wheel and rail. In the same way, the constructional components can be compared: In opposition to extensive, costly and high-maintenance fixed installations, namely overhead contact system (or permanent way, respectively) we have relatively simple and small equipment which are clear and uncomplicated in construction, namely pantographs (or wheels and bogies of vehicles, respectively). It is therefore important to design pantographs (or running gears of vehicles) in such a way that optimum results can be achieved for the entire system of current transmission.

The current collection quality (exploitation of the friction coefficient) of the guided pantograph is the result of its design and especially of the conditions established by its guidance, the overhead contact system. Forces resulting from the interaction of pantograph and overhead contact system are, on the one hand, decisive for the current transmission capability and for the operating safety of the pantograph, and on the other hand for the stress exerted on the overhead contact system and for its operating safety.

Wear and maintenance of pantograph and overhead contact system depend on the magnitude and frequency of these forces occurring between contact strip assembly of the pantograph and overhead contact system.

The increase of speeds in railway operation generally results in a higher stress on pantographs and overhead contact systems (the same applies to track and running gear), especially if development work was not carried out under the aspect of high speeds or if knowledge concerning technical conditions or concerning the dynamic behavior of occurring forces was not sufficient. Type and effects of interference points in overhead contact systems (or tracks) influence the current collection quality. The numerous reciprocal influences, as for example, uplift forces, dynamic oscillatory behavior, conditions of elastic coupling with regard to the pantograph, as well as elasticity, accuracy of position and mass distribution of the overhead contact system have to be determined on the basis of operational experiences.

By theoretical investigations the interaction of pantograph and contact wire can be detected only partially, because these investigations are carried out under idealized conditions. Irregularities and errors of position of the overhead contact system can not be detected. Measurements and, above all, a logical and consequent detection of errors, furthermore the evaluation of errors which occurred in operation as well as a resulting advancement of individual components all are most important for the pantograph als well as for the overhead contact system.

The <u>DB standard pantograph type DBS 54</u> was designed in 1953/54 for speeds up to 160 km/h (figure 1).

The simple design of the pendulum suspended pan which was introduced at that time has the disadvantage of an excessive pan deflection at high running speeds caused by friction at the contact wireand by atmospheric pressures of the wind leading to an insufficiently suspended working range of the pan. In cases of minor irregularities of the contact wire the pan already bounces, resulting in voltage interruptions. The forces produced during this process lead to cracking of carbon strips. From this it is obvious that contact strip assemblies of previous types, where a carbon strip is clamped into a sheet frame, are not able to withstand the forces occurring between overhead contact system and pantograph. Approx. 30 to 40 % of these contact strip assemblies have to be replaced prematurely because of more than one crack. The average service life of this type of contact strip assembly which still is installed in more than 90 % of pantographs is approx. 65 000 km. A further weak point of these contact strip assemblies was their fastening to the pan. In several cases the natural oscillations of the pan led to loosening of fastening screws resulting in considerable damage to the overhead contact system.

However, it was possible to eliminate these deficiencies by a new design with carbon contact strips soldered to a beam and with improved fastenings by higher strength screws and friction nuts. Besides, the corner weld joints at the contact strip were improved by more favorable weldings. These constructional changes were the basic prerequisites for further development. The new soldered contact strips, of which you see several versions here, achieve a service life of more than 100 000 km. They are completely immune against crack formation leading to a considerable reduction of routine inspections.

For reasons of tradition, the frame design of the DBS 54 is heavy in weight and sturdy and this frame therefore shows difficulties in following the abruptly occurring irregularities of the contact wire. It determines the statical contact pressure of the pan. Over the entire vertical pan movement of 2,76 m this design allows a statical contact pressure of 3,4 to 3,5 kg per contact strip. To this statical contact pressure an aero-dynamical force is being added which is the result of the running speed and of the shape of the contact strip assembly and which, at a speed of 100 km/h amounts to approx. 0,5 kg and at a speed of 200 km/h to approx. 3 kg per contact strip. These aero-dynamical uplift pressures may partially be compensated by wind deflector plates attached to the horns, but this arrangement leads to certain vibrational forces.

In 1965 we carried out trial runs with 12 different types of pantographs and pans, respectively, in order to find a suitable design for speeds up to 200 km/h (figures 2-7).

During these test runs the contact pressure and the current transmission quality which were stipulated as number and duration of voltage interruptions were determined in a simple manner.

For the high-speed locomotive E 103 we selected a pantograph DBS 54 with Wanisch-pan (figure 3) which gave the best results on a test section where the overhead contact system was very well adjusted. In practical operation serious cracks were observed at pan components caused by the rigidly suspended pan articulation and leading to the elimination of this pan design. The pantograph was replaced by the Siemens-design SBS 65 with a pan of light-weight construction.

The pantograph SBS 65 has the following advantages (figure 10):

Articulation of the pan to the single arm by means of a torsion element with rubber spring (Rostaelement). Minor variations in the height of the overhead contact system caused by sag are exclusively compensated by the pan springs. Pan and horns in light-metal with soldered contact strip assemblies.

Compared to the steel construction this design provided weight savings of about 30 %.

Single arm pantograph with less mass and less air resistance.

With the single arm construction - with regard to the statical contact pressure- a more favorable rod design can be achieved than with the crossed arm construction.

Smoother operation of the pantograph at lowered heights of the overhead contact system (for example, at bridges) by use of a shock absorber in the lower frame.

Fewer and considerably shorter voltage interruptions (advantage with regard to electronic components in locomotives). Option of space saving fastenings at the roof by means of 3 fastening points for the insulators.

Further development of all components is very well possible with this type of pantograph having a small number of joints which can accordingly be designed sturdy and shock absorbing. The articulation of the pan can be carried out by means of simple levers supported by shock absorbing bearings.

In utilization of different types of overhead contact systems, the Bundesbahn-Zentralamt München carried out test runs of 250 km/h with this pantograph.

Measurements of forces occurring between contact wire and pantograph as well as measurements of the pantograph behavior in regard to movement and oscillation were recorded by means of strain gauges, piezoelectric gauges and potentiometers and - out of the 15 kV range - were transmitted through a FM-telemeter installation with a fundamental frequency of 235 MHz.

At a speed of 250 km/h the average vertical contact pressure of the front contact strip was approx. 85 N and of the following contact strip approx. 80 N.

With regard to the overhead contact system on the open line, the band width of contact pressure was between 25 N and 185 N. In train stations the maximum forces measured were 245 N.According to the measurements, the longitudinal forces amounted to an average of 80 N with a band width of 25 N to 235 N. The maximum values of transverse forces at the pan fixing points were ± 185 N.

Frequency analysis resulted in the following main frequencies:

- vertical force: 29 Hz and 82 Hz
- longitudinal force: 82 Hz (natural resonance)
- transverse force: 5,8 Hz

During this series of measurements it was also possible to detect the influences of shock absorber forces in points of lowered height of the overhead contact system (at bridges). Of great importance was the discovery that the natural resonances of individual components have an influence on the running qualities and therewith on the current collection quality.

By means of these test results a further development is possible.

There is one more statement to be made with regard to pantograph development:

Test runs at high speeds, expenditures necessary for measurements at the pantograph as well as storage and evaluation of measurement data result in very high cost which can not be allotted to the relatively simple and rather economy-priced component "Pantograph". Furthermore, the number of pantographs to be manufactured is fairly low. It is therefore necessary to provide separate financial funds for the development of high-speed pantographs. In our opinion, the cost for development and for the necessary test runs will amount to more than 1 million marks.

Cu 15kg
Aluminum,
Total 200kg
2.76 m Range

ATTACHMENT 3

Dipl.-Ing. Güthlein

Deutsche Bundesbahn
Bundesbahn-Zentralamt München
21

Electric locomotives with thyristor phase-angle control and with extinguishable, unsymmetrical bridge (LUB)

Gentlemen,

For the international railway traffic between SNCF, CFL and DB with two traction current systems (16 2/3 Hz, 15 kV and 50 Hz, 25 kV) the German Federal Railway put into operation 25 two-system locomotives type E 181-2 in the years of 1974 and 1975.

The operation of these locomotives extends from hauling of high-speed passenger trains with speeds of 160 km/h to the hauling of heavy freight-trains for the mining industry with loads of 2 000 t and with speeds of 80 km/h. The requirement of universal application made on this locomotive unavoidably led to a rectifier driving technique with undulating current traction motors and with phase-angle controlled thyristor rectifiers. Locomotives with a.c. commutator motors can be operated only at a low frequency of 16 2/3 Hz and are furthermore not able to fullfil the required universal tasks of traction (e.m.f. of transformation).

Therefore, current converter installations are indispensable for the universal utilization of tractive units. Despite the relatively small power of the locomotive E 181-2 amounting to 3 200 kW this locomotive meets the traction requirements because of the favorable characteristic of tractive effort/speed.

The development of this rectifier technique for locomotives was started in 1963. Already in 1966 5 prototype locomotives E 181-1 were delivered. The evaluation of operational experiences gained with this prototype showed that the advanteagous traction behavior is related to an unfavorable behavior of the network. Already at that time solutions were sought for analyzing repercussions on the power supply network, on telephone installations and on signaling installations and for reducing their effects on the tractive unit and on fixed installations. Harmonic vibrations caused by the rectifier operation result in additional heat losses in the tractive unit and in the network; d.c. current and d.c.voltage for the supply of traction motors are charged by harmonics which increase losses and exert a negative influence on the commutation of traction motors. It was possible to improve the locomotive 181-2 by installing a self-inductor with larger inductivity resulting in smaller repercussions on the network. Because of the fact that the effective value of the traction current is a result of fundamental oscillations and harmonics the power factor can be improved if harmonic vibrations are reduced. If the relation of d.c./a.c. self-induction Lg/Ls is increased this results in an improvement of the power factor. In the case of a low network frequency (16 2/3 Hz) it is for reasons of economy and weight not possible to achieve a satisfactory value fcr the d.c. self-induction. In the same way, the short circuit voltage of the transformer can not be reduced considerably which means that a smoothing value Lg/Ls of only 15 can be obtained. With this measure it is not possible to achieve a decisive improvement of cos φ_1.

In the case of the locomotive E 181-2 repercussions of harmonics of higher order on telephone installations, i.e. the so-called psophometric interference current, is within the admissible limits of $\boxed{\text{4-5 A}}$ (at doubling of 50 Hz). By installing suppressor filters this value could be further reduced but this is not necessary within the operational range of the DB.

Influences on DB signaling installations which are being operated with 100 Hz track-circuits occur only in case of considerable interferences in the rectifier control or in the rectifier itself. In these cases, a 100 Hz current-supervision system disconnects the rectifier installation before signals are influenced.

$I_{100} > 2A$ and $t > 0,5$ sec).

The unfavorable values of the power factor λ led in 1971 to the development of self-commutating rectifiers in bridge circuits.

Theoretical investigations and developments in laboratories led to the conclusion, that in the case of such rectifiers it is possible to influence the current fundamental oscillation in such a way that the displacement factor $\cos \varphi_1$ can be raised to 0,95 or 1 over a wide range. On the basis of these findings the rectifiers of the commissioned 25 two-system locomotives 181-2 were so designed that components for self-commutation could be installed without problems at a later date. During delivery of the locomotives 181-2 two locomotives were equipped with the additional system for self-commutation (LUB). These considerations were confirmed by test runs (figure 1).

It was possible to considerably improve $\cos \varphi_1$ and the power factor λ from approx. 0,82 to 0,95. Beginning at a speed of 20 km/h minimum values were raised from 0,64 to 0,78.

The psophometric interference current Ipe increased somewhat to 5,5 A and even to 7 A (without LUB 4 A to 5 A) because of the second half-wave extinction point. In the 50 Hz-network Ipe is doubled.

The extinguishable, unsymmetrical bridge (LUB)

In the case of rectifiers with LUB, thyristors are ignited in usual manner by varying the ignition time according to the voltage requirements. However, extinction is not automatic during current crossover, but rather at a selectable earlier instant by ignition of extinguishing thyristors (forced commutation) extinguishing the main thyristor concerned by means of the charging energy of a capacitor. The surplus charge of this capacitor is discharged through the d.c.-circuit via inductance and motor. This forced extinction of the main thyristor abruptly interrupts the circuit of the bridge, the existing magnetic energy has to be stored in other capacitors and - by additional ignition of the main thyristor - can be fed into the traction motor circuit.

By this forced extinction of the main thyristors which is performed at an earlier time the center of the current-time-range shifts towards the center of the voltage-time-range leading to a reduction of the reactive power.

The time of extinction can be fixed definitely, or - if conditions require - (because of load, control or λ) it can be changed in order to be able to specify the power factor.

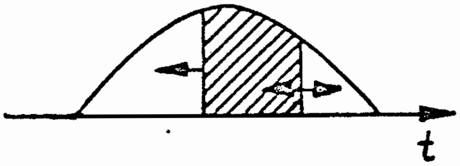
Extinguishing a LUB with set extinction time requires the least expenditure in control electronics.

There are extinguishing circuits available with one, two or three capacitors. These can be selected with regard to economy. The most favorable network condition but also the largest expenditure is to be found with the three-capacitor-circuit (3 C-LUB). A 2 C-LUB was considered the most economic solution for the locomotive E 181-2.

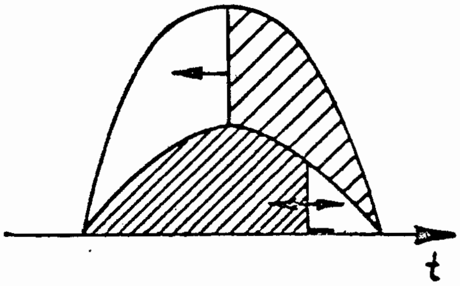
2 C-LUB

If the extinction of the main thyristors is to be carried out without preliminary ignition of these main thyristors - as is the case with the 1 C-LUB - charging of the extinction capacitors has to be carried out through a charging resistor. The extinction circuit has been expanded by adding the charging resistor v_1 and the charging diodes n_3 and n_4. With this extinguishing system it is possible to extinguish the main thyristors during each period at a given time t_L previous to the voltage crossover. In this case, the possible maximum extinction angle is again determined by the magnetic energy and by the associated capacitor voltage. Because of the fact that extinction occurs shortly before the crossover of the supply voltage the voltage surge caused by the forced extinction of the main thyristors is relatively low. The success of power factor improvement depends on the extinction current possible. Therefore, the extinction system is installed in the first bridge.

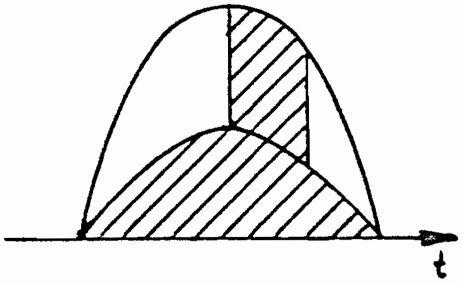
1. Brücke



1. u. 2. Brücke



result. Bild 1. u. 2. Brücke



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The control for the power electronic has been installed in a dust-proof cabinet equipped with cooling-air circulation and with the associated heat exchanger. An adequate, safe and clean casing is of special importance to the efficient operation of electronic controls. An excellent accessibility was achieved by a swivel frame construction installed in the driver's cab. The control electronic, type "Geotronik" consists mainly of integrated circuits according to the standard system "Logidyn". This control equipment proved well up to the present.

Measuring results and operational experiences gained over a period of almost two years showed that rectifier-supplied tractive unit drives can be designed in such a way, that loads on the network caused by the factor $\cos\varphi_1$ will not be higher than in the case of drives with a.c. commutator motors. This aim was achieved with a relatively low increase of expenditures necessary for power- and control electronics.

Interference currents disturbing telecommunication- and signaling installations were within a range which is acceptable for operation on DB-lines.

ATTACHMENT 4

Technical Details

Designation:	403/404/404/403
Arrangement of the basic unit	ET+ETM+ETM+ET
Wheel arrangement	$B_o'B_o'+B_o'B_o'+B_o'B_o'$
Current	single-phase a.c. 15 kV - 16 2/3 Hz
Vehicle gauge	No.II, Annex 9 of the rules for railway constructions and operation (EBO)
Maximum speed	200 km/h
Overall length of train	109.22 m
Number of passenger seats	183 (1st class only)
- thereof in the dining compartment	24
Length of end car	27.45 m
Length of centre car	27.16 m
Pivot pitch	19 m
Width of car body at 1000 mm above rail level	2795 mm
Floor height above rail level	1300 mm
Bogies	2 wheel sets, mounted on pneumatic suspension with blocking of side motion
Wheel-base of bogie	2600 mm
Wheel diameter	new 1050 mm worn 1000 mm
Minimum radius of negotiable curve	120 m
Weight in working order	235.7 t, approx.
Average axle load	14.7 Mp
Motor plants	4, one per car

Number of traction motors	4 x 4 = 16
type	Undulating current motors with series- and separate excitation
Cooling	self-cooling
Transformers	4, each offering the following individual output: Traction 1000 kVA Air-conditioning 100 kVA Auxiliaries 75 kVA Separate cooling by oil cooler
Control	Thyristor-phase angle control with two unsymmetrically half controlled bridge rectifiers in sequence control per car; field control
Propulsion	Unidirectional cardan shaft transmission with rubber-ring
Rated output of traction motors with air-intake case (VDE-Standard 0535 = continuous output) at 139 km/h and excitation of 81 %	16 x 240 kW = 3840 kW
Constant current of one motor	350 A
Maximum starting current of one motor	550 A
Maximum braking current of one motor	650 A
Maximum motor voltage at starting	
Minimum excitation	41 %
Maximum starting power of a motor-coach train at 110 km/h, approx.	6000 kW
Maximum braking power of a motor-coach train from 200 to 150 km/h, approx.	10 000 kW
Maximum starting tractive effort of the motor-coach train	20.2 Mp (16 motors)
Acceleration during running	0.6 m/s^2 (0 ...200 km/h) 0.45 m/s^2 (110...200 km/h)

Electric circuit of the motor-coach train	Three-phase current 50 Hz 220 V, between phases
Types of brakes:	
Electric brake	Rheostatic brake dependent on the contact wire and combined with an electro-pneumatically controlled supplementary compressed-air brake
Compressed-air brake (safety brake)	Graduated compressed-air disc brake with automatic braking of the load and with electronic skid device
Electro-magnetic rail brake	2 magnets per bogie
Hand brake	Acting on one bogie per car
Maximum power of electric brake	24.8 Mp
Application of supplementary compressed-air brake at approx. 145 km/h	
Rapidity of braking from 200 to 0 km/h	0.7 m/s^2 (electric brake plus supplementary compressed-air brake)
Maximum average rapidity of braking from 200 to 0 km/h	0.9 m/s^2 (electric brake plus supplementary compressed-air brake)
Rapidity of quick-acting brake from 200 to 0 km/h	1.25 m/s^2 (compressed-air brake plus electro-magnetic rail brake)
Combined draw and buffing gear	Automatic central buffer coupling, type Scharfenberg
Material of coach body	Lightweight-metal (Al Zn Mg 1 and Al Mg Mn)
Construction	Welded, integral construction with large extrusions
Interior design of coaches	Same conception as in new DB passenger stock with high comfort
Side walls	Integrated elements made of glass fiber-reinforced plastic material

Partition walls	Wooden panels with foil covering which has a velvety layer of polyamide	
Air-conditioning (specifications per car)	Weight:	1.6 t
	Air output:	2000 m^3/h
	Heating power:	43 kW
	Cooling power:	20 000 kcal/h

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ATTACHMENT 5

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Bundesbahn-Zentralamt München
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Continuous automatic train running control

The continuous automatic train running control (LZB) is designed for the continuous exchange of information between the running train and one or several fixed operating control posts. This enables operating control posts to continually know the location and speed of trains running in their control area and to control train operation by specifying the theoretical speed values or a stop; it furthermore enables them to supervise the compliance with the specified theoretical values.

These theoretical values are optically displayed in the driver's cab (cab signaling) and through the automatic running- and braking-control (AFB) it is possible to directly transmit them to the vehicle control equipment. The previous optical recognition of signals is replaced by an "electrical sight" over a theoreticall optional distance, enabling an operation at speeds of more than 300 km/h.

The LZB-system therefore fulfills tasks concerning train safety, solves problems concerning operating control, allows higher speeds while retaining existing signal systems and, in connection with AFB, reliefs the driver from routine tasks.

Within the scope of the tasks of the continuous automatic train control information has to be transmitted from the line to the trains.In so-called operating control posts or in computer centers this information which is collected from signal boxes and from the line, for example, red signal aspects, admissible maximum speeds, gradients etc., is converted into running commands and is transmitted to the vehicle. This transmission of information is achieved by means of a continuous conductor layed in the track. This conductor consists of two single-wire cables layed in the middle of the track and in the flange of the rail, respectively. By antennas mounted on the vehicle the messages modulated on carrier frequencies of 36 and 56 c.p.s. can be exchanged in form of impulse telegrams. The two conductors layed in the track are crossed every 100 meters. In this way it is possible to substantially compensate for electrical interferences which may couple in the conductor. Furthermore, these crossing points are being used as synchronizing points for the necessary location of vehicles. The crossings are being counted by the vehicle equipment. This gives an indication of the vehicle location (= sections of 100 meters each). Information on the vehicle location is being transmitted indirectly to the control system in form of a repeater telegram.

The conductor forms a loop with a maximum length of 12,7 km. This means that 127 of the afore-mentioned 100 meter-sections (also called locations) form a loop or control area. Longer lines have to be equipped with a plurality of successive loops. The LZB-control system provides each one of these loops with information. If there are several LZB-equipped vehicles in one section of 12,7 km it has to be assured that individual vehicles receive and process only running commands addressed to them. This is achieved by indicating the location of a given vehicle on the command telegram. All trains running in the section take notice of the transmitted telegrams but reject them if they do not indicate the location last reported by the vehicle. This method is designated as addressing with regard to location, In this way, one control center can provide information for a maximum of 9 trains running in one control area.

A pulse telegram transmitted from the line to the vehicle consists of 83,5 steps or bits, 8,5 steps of which are allotted to synchronization (recognition of the telegram start), 67 steps are allotted to the message proper and 8 steps to code supervision. The duration of the telegram is approx. 70 ms. Because of the short duration of one telegram it is possible to address every vehicle every second with new information, even if the loop is fully occupied. The message transmitted to the train provides the possibility to send running commands for speeds up to 315 km/h. The specified speeds are continuously supervised. Exceeding of this speed results in an automatic emergency braking. In order to better inform the driver and for the purposes of automatic train operation further information is being transmitted, as for example, target distance, target speed and other additional information.

Vehicles confirm the receipt of running commands by sending pulse telegrams to the control system. These telegrams contain the afore-mentioned confirmation of train location and other train data which are necessary for the preparation of running commands, as for example, train length, braking capacity, actual speed. The repeater telegrams consist of 41 telegram steps of which 6 steps are allotted to synchronization, 28 steps to the message proper and 7 steps to supervision. The duration of this telegram is again approx. 70 ms.

These repeater messages from the train to the line provide a constant supervision over the train operation and over the correct functioning of all instruments. In this way it is also possible to operate trains running in succession on electrical sight. With this running on electrical sight the headway of trains can be kept within the limits of the absolute braking distance, i.e. as soon as the first train starts to move the following train can also start.

Equipment used in signal boxes and vehicles are designed in the technique of fail-safe circuitry.

Instruments in the signal box are designated as control centers. As already mentioned, they each deliver information to two conductor loops of 12,7 km length and to two sidings. This limitation is caused by the circuitry-technique which implies a plurality of components leading to a reduction of equipment availability.

The present development aims at centralizing equipment concerning the line. By the use of freely programmable process computers it will be possible to centralize larger areas in so-called LZB-computer centers. This means for example, that, contrary to the conventional operating control posts it will be possible to provide not only 9 but 72 trains and not only 4 but 16 conductor loops with information from one single computer center.

With computer-controlled operation, in order to meet the specifications concerning signaling techniques, orders and running commands have to be computed by two separate computers working with different programs for the quick detection of faults. Therefore, a computer center has to consist of at least two computers. A third computer can serve as stand-by in case of failure of one computer, which means that the safe two-computer operation and therewith the safe train operation can be continued without impairment. In a standard case all three computers calculate identical output commands which prior to output are being compared by a majority- and supervising-circuitry (two-out-of-three-comparison).

Concerning the software, the operation program, the work programs and the fixed and variable data lists of the line are elaborated for maximum system extension and maximum traffic loads. Therefore, the system is universally applicable without the necessity of program changes. Only the local list of lines has to be elaborated anew for each individual application.

To the present, the German Federal Railway equipped 260 line kilometers and about 190 vehicles with LZB at a cost of approx. 70 million marks.

Dr.-Ing. Weigend, Dez 81

ATTACHMENT 6

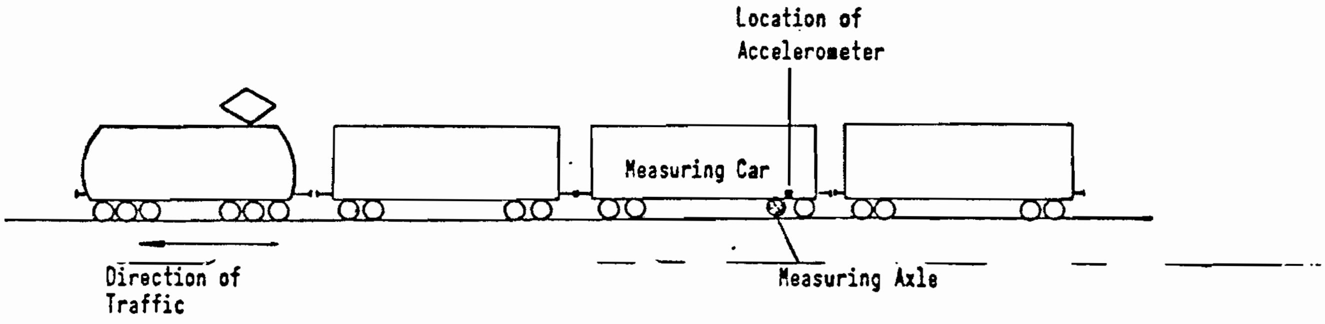
Acceleration measurements for quality control in the high speed DB-network

1. Introduction

In connection with the increasing speeds and traffic loads it became evident, that the requirements to be met by the permanent way are also increasing to a high degree. Experiences have shown that in addition to regularly inspecting the track geometry it is also necessary to directly measure the influence the track condition exerts on vehicles running at high speed. For this reason, DB carries out measurements of acceleration and forces on high speed lines. From the reactions of vehicles conclusions may be drawn concerning the geometrical deficiencies of track alignment. Local deficiencies of track alignment where the accelerometer equipment registers high values require an immediate or soon restoration of the permanent way condition.

2. Design and operation of the measuring equipment

The measuring equipment is installed in a passenger coach running in the middle of a train-unit consisting of three cars.



This measuring equipment consists of the following instruments:

- accelerometer
- instrument for measuring transverse forces of axle-bearings
- measuring amplifier
- magnetic tape store
- recording oscillograph

The accelerometer is mounted on the car floor above the second bogie,viewed in running direction,Transverse forces of axle-bearings are being measured by strain gauges attached to special measuring pins in the axle-bearing.

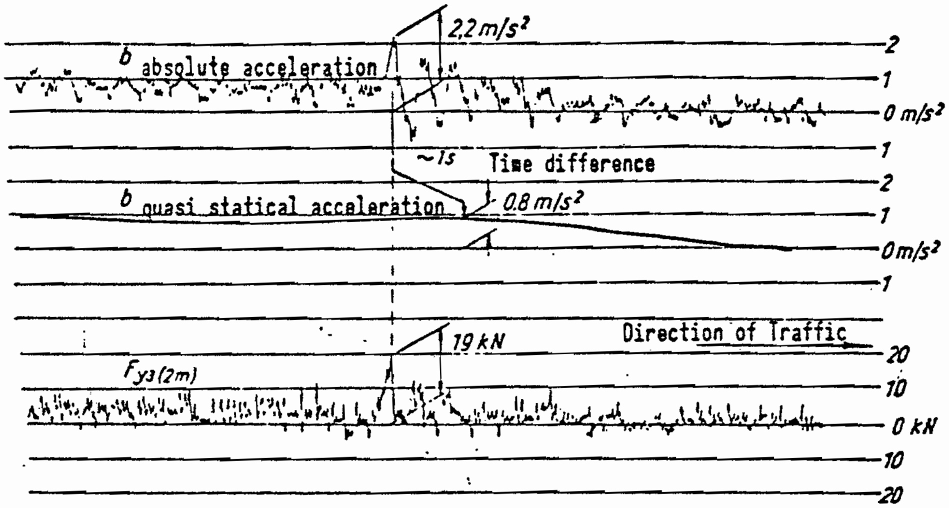
Frequencies exceeding 16 Hz are being filtered out because they are insignificant for the evaluation of the running qualities of a vehicle. Therefore, during runs at maximum speed, we record only forces and accelerations which occur over distances of approximately 2 meters or more.

The measured values obtained in this way are being registered as lateral acceleration "absolute b" and as transverse force of the axle-bearing F_{y3},recorded at the third axle,viewed in running direction.

To facilitate evaluation the oscillations of lateral acceleration are additionally being filtered by means of a 0,5-Hz-filter and are separately recorded as "quasi-statical" lateral acceleration "quasi-statical b". This quasi-statical lateral acceleration corresponds to the mean value of the absolute lateral acceleration. Depending on the rolling angle of the car body the measured value may be 30 to 40 % larger than the value of the "excess" lateral acceleration calculated from the insufficiency of cant $\ddot{u}_f$.

$$\text{Quasi-statical } b \approx 1{,}3 \cdot bo.$$

The dynamic share of lateral acceleration "$_{\text{dyn}}b$" is an oscillation superimposed on the quasi-statical portion; the value of this dynamic share is equivalent to the difference between the total value and the quasi-statical portion: $_{\text{dyn.}}b = {}_{\text{absol.}}b -$ quasi-statical b.



The measuring equipment was especially developed for the detection of errors in track alignment. If the "tripping limit value" is exceeded it is not sufficient to only register the peak reading but it is rather necessary to also display environmental data.

This is done by means of a magnetic tape store which stores the measured values for a period of approximately 10 seconds. If the tripping limit value is exceeded the measured values are being registered by means of a recording oscillograph. In this way it is possible to display the pattern of oscillations occurring in front of and behind an interference point in the track.

3. Analysis of measured values

The design of the measuring equipment permits any desired threshold value to be used as tripping limit value.

In the case of the quasi-statical lateral acceleration the value of 1,2 m/s^2 corresponds to an insufficiency of cant of 130 mm if an addition of ~40 % is assumed for the rolling motion of the car body. The limit value of 1,2 m/s^2 can virtually not be exceeded unless the running speed in the curve is too high. At these locations it will always be necessary to introduce speed restrictions.

While accelerations occurring in the car body mainly affect the riding comfort, measurements of the transverse forces of axle-bearings F_{y3} have the purpose of directly checking the operational safety.

In consideration of the stability of ballast tracks and according to Prud'homme the transverse force of an axle-bearing shall not exceed :

$$F_{y3} = 0,85 \left(10 + \frac{2Q}{3}\right) \quad [kN]$$

where 2Q = axial force in kN.

It has been shown that transverse forces of axle-bearings are very seldom the only tripping criterion, i.e., if transverse forces of axle-bearings are exceeded it generally results also in exceeding of the acceleration limit values.

The tripping limit values of the accelerometer equipment and the steps to be taken - which again depend on the degree of exceeding the limit value - are shown on the following chart.

		straight line		curved line			
		b_{dyn}	F_{y3}	b_{dyn}	b_{quasi}	b_{abs}	F_{y3}
		m/s^2	kN	m/s^2	m/s^2	m/s^2	kN
1	tripping limit values:	1,3	25	1,3	1,2	2,0	25
2	measures for maintenance	> 1,5	> 25	> 1,5	-	> 2,3	> 25
3	speed restrictions *)	> 2,5	> 35	> 2,5	≧ 1,3	> 3,5	>35
4	*) exceptional cases:	2,5./.3,0	26./.35	2,5/.3,0	-	3,5./.4,0	-

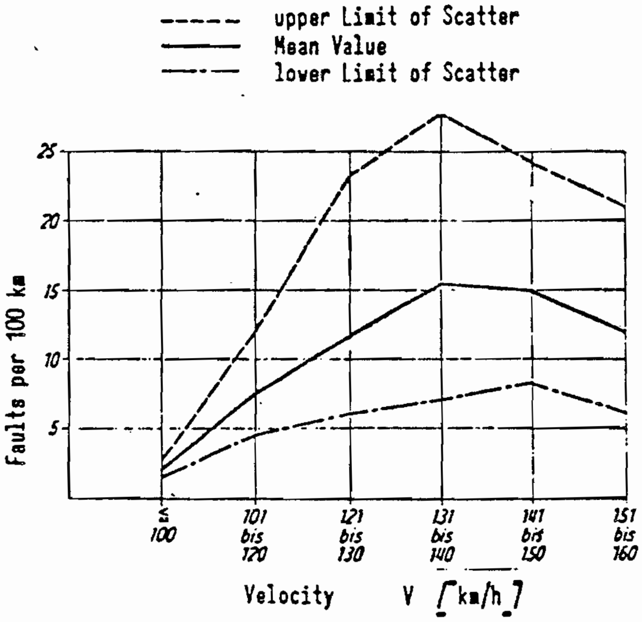
If the limit values for maintenance indicated in line 2 are exceeded it is necessary to take immediate steps in order to clear the fault. Depending on the traffic density of a line and depending on the degree of exceeding the measurement value these steps have to be taken in good time in order to avoid speed restrictions which - in a given case - have to be introduced according to line 3. If the measurement value is exceeded only to a limited extent it is by way of exception permissible to refrain from introducing a section of speed restriction in order to maintain the traffic flow (see line 4).

4. Experiences gained from acceleration measurements

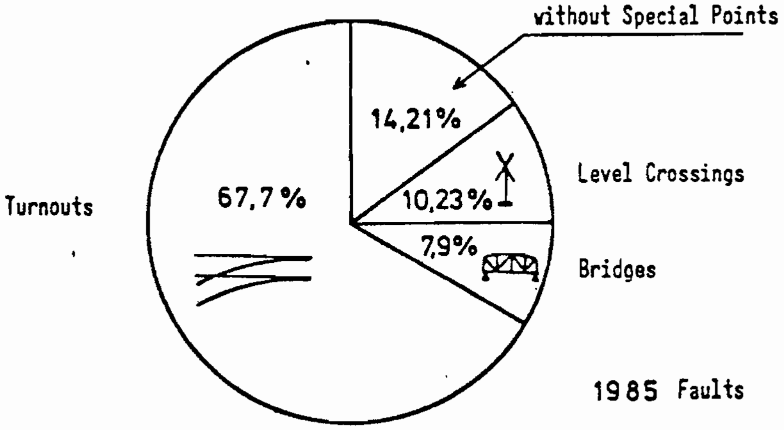
By acceleration measurements it is possible to immediately detect the effects alignment deficiencies have on the smooth running of a vehicle, enabling the maintenance staff to considerably improve the track condition with little expenditure.

While in the case of speeds up to approximately 120 km/h the previous practice of checking the track geometry was sufficient it is in the case of higher speeds necessary to carry out more frequent and objective checkings by means of measurements of accelerations and forces. The determination of track-geometrical "operation tolerances" is not suitable for determining the admissibility of a given running speed. In the case of high speed lines the proof of safety has to be furnished primarely by measuring vehicle reactions during operation with the admissible maximum speed. However, if a satisfactory track alignment is to be guaranteed in the high speed range as well as in the lower speed ranges it is necessary to observe the specified "Standard Values for Maintenance". These "Standard Values for Maintenance" are stipulated for the individual geometrical parameters which are being registered by the existing measuring cars.

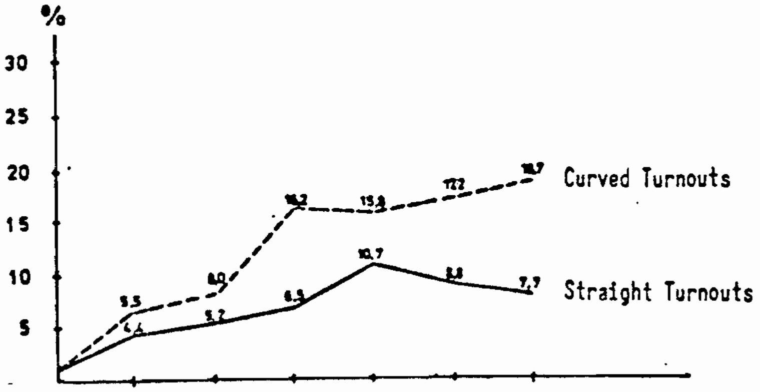
The following graph shows the number of faults per 100 km of track length, subdivided into the different speed ranges:



The largest percentage of faults (nearly 90 %) is caused by special points located in the lay-out of the line. As can be seen from the following graph, turnouts have the largest share in these faults:



A comparison of faults in turnouts shows that at speeds up to 120 km/h the susceptibility of curved turnouts is almost equivalent to that of straight turnouts. In higher speed ranges (V ≥ 130 km/h) the susceptibility of the curved turnout increases rapidly (see graph below). Sections with a greater number of straight or curved turnouts arranged in succession are far more susceptible to deficiencies in track alignment; this applies to an even higher extent if branch lines also carry heavy or dense traffic.



The future aim is to combine measurements of acceleration and track geometry. However, in this connection it is prerequisite that the track measuring car is so designed that it is able to record geometrical data on the line at the admissible maximum speed.

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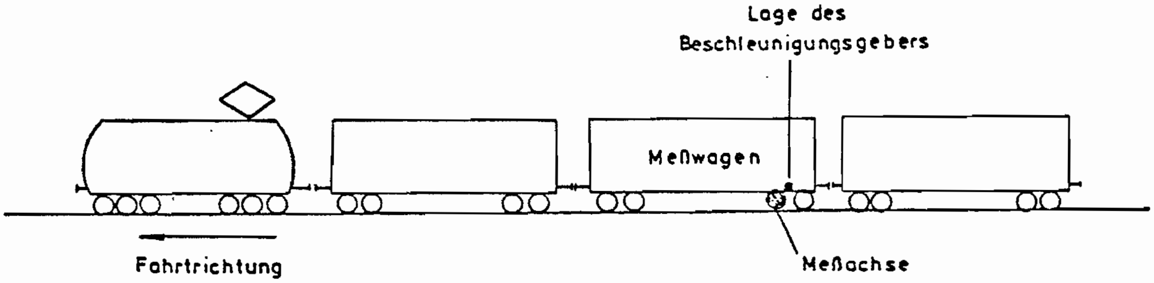
Beschleunigungsmessungen zur Qualitätskontrolle im schnellbefahrenen Netz der DB

1 - Einleitung

Im Zusammenhang mit der Erhöhung der Geschwindigkeit und der Belastung hat sich herausgestellt, daß die Anforderungen an den Oberbau im hohen Maße ansteigen. Die Erfahrungen zeigen, daß neben der regelmäßigen Kontrolle der Gleisgeometrie, zusätzlich der Einfluß des Gleiszustandes auf das mit Höchstgeschwindigkeit fahrende Fahrzeug unmittelbar gemessen werden muß. Zu diesem Zweck werden bei der DB im schnellbefahrenen Streckennetz Beschleunigungs- und Kraftmessungen durchgeführt. Aufgrund der Fahrzeugreaktionen wird versucht, Rückschlüsse auf die geometrischen Gleislagefehler zu ziehen. Örtliche Gleislagemängel, an denen die Beschleunigungsmeßanlage große Werte anzeigt, erfordern eine sofortige oder baldige Instandsetzung des Oberbauzustandes.

2 - Aufbau und Wirkungsweise der Meßanlage

Die Meßanlage ist in einem Reisezugwagen eingebaut, der in der Mitte eines Zuges, bestehend aus drei Wagen, fährt.



Sie besteht aus
- dem Beschleunigungsaufnehmer,
- der Meßeinrichtung für die Achslagerquerkraft,
- dem Meßverstärker,
- dem Magnetbandspeicher und
- dem Registrier-Oszillographen.

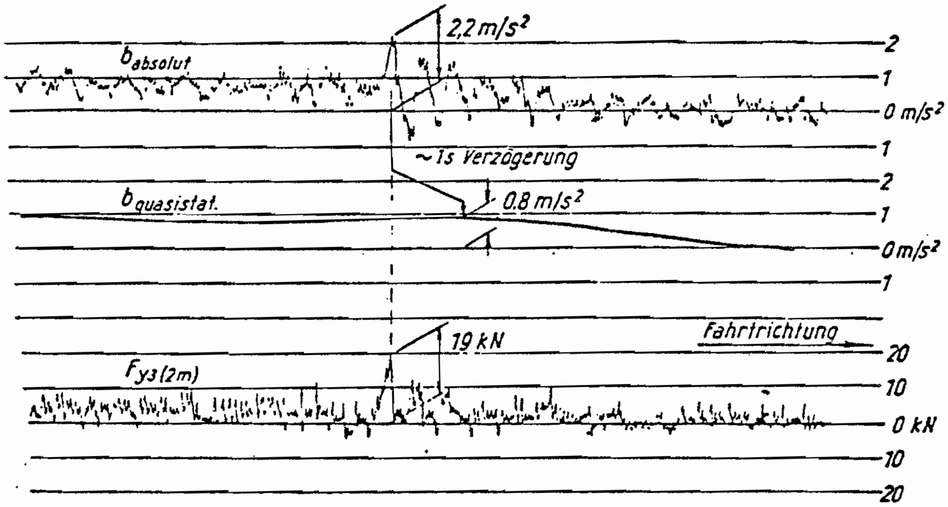
Der Beschleunigungsaufnehmer ist auf dem Wagenfußboden jeweils über dem nachlaufenden Drehgestell angebracht. Die Achslagerquerkräfte werden mit Hilfe von Dehnungsmeßstreifen gemessen, die auf besonderen Meßbolzen im Achslager befestigt sind.
Frequenzen von mehr als 16 Hertz werden herausgefiltert, da sie für die Beurteilung des Fahrzeuglaufes ohne Bedeutung sind. Somit werden bei Höchstgeschwindigkeit nur Kräfte bzw. Beschleunigungen registriert, die über eine Wegstrecke von etwa 2 m und länger anhalten. Die so erhaltenen Meßwerte werden als Seitenbeschleunigung "absolut b" und als Achslagerquerkraft Fy_3 an der 3. Achse, in Fahrtrichtung gesehen, registriert.

Zur leichteren Auswertung werden die Schwingungen der Seitenbeschleunigung zusätzlich noch mit einem 0,5-Hertz-Filter gefiltert und als "ausistatische" Seitenbeschleunigung "quasistatisch b" besonders aufgezeichnet. Diese quasistatische Seitenbeschleunigung entspricht dem Mittelwert der absoluten Seitenbeschleunigung. Bedingt durch den Wankwinkel des Wagenkastens kann der gemessene Wert nur 30 bis 40 % größer sein als der aus dem Überhöhungsfehlbetrag $\ddot{u}_f$ errechnete Wert der "überschüssigen" Seitenbeschleunigung.

quasist. $b \sim 1{,}3 \cdot b_o$

Der dynamische Anteil der Seitenbeschleunigung "dyn b" ist eine dem quasistatischen Anteil überlagerte Schwingung; sein Betrag ist gleich der Differenz zwischen dem Gesamtwert und dem quasistatischen Anteil

dyn ^{b} = absol. ^{b} - quasist. ^{b}



Die Anlage ist besonders für das Auffinden störender Gleislagefehler entwickelt. Wird der "Auslösegrenzwert" überschritten, so genügt es nicht, allein den Spitzenausschlag selbst festzuhalten, vielmehr müssen auch die Werte der Umgebung dargestellt werden.

Dies geschieht mit Hilfe des Magnetbandspeichers, der die gemessenen Werte rund 10 sec. lang speichert. Bei Überschreitung des Auslösegrenzwertes werden die Meßgrößen mit Hilfe des Registrieroszillographen aufgezeichnet. Hierdurch ist es möglich, den Schwingungsverlauf vor und nach einer Störstelle im Gleis darzustellen.

3 - Auswertung der Meßergebnisse

Der Aufbau der Anlage läßt jeden beliebigen Schwellenwert als Auslösegrenzwert zu.
Bei der quasistatischen Seitenbeschleunigung entspricht der Wert 1,2 m/s^2 einem Überhöhungsfehlbetrag von 130 mm, wenn ein Zuschlag für das Wanken des Wagenkastens von ~ 40 % angenommen wird.
Der Grenzwert von 1,2 m/s^2 kann praktisch nur überschritten werden, wenn die Fahrgeschwindigkeit im Bogen zu groß ist. Hier wird stets eine Geschwindigkeitsermäßigung notwendig sein.
Während die Beschleunigungen im Wagenkasten in erster Linie den Fahrkomfort beeinflussen, dient die Messung der Achslagerquerkräfte F_{y3} zur unmittelbaren Kontrolle der Betriebssicherheit.

Mit Rücksicht auf die Lagestabilität des Schotterbettgleises darf nach Prud'homme die Achslagerquerkraft den Wert

$$F_{y3} = 0,85\,(10 + \frac{2Q}{3}) \quad [kN] \; ;$$

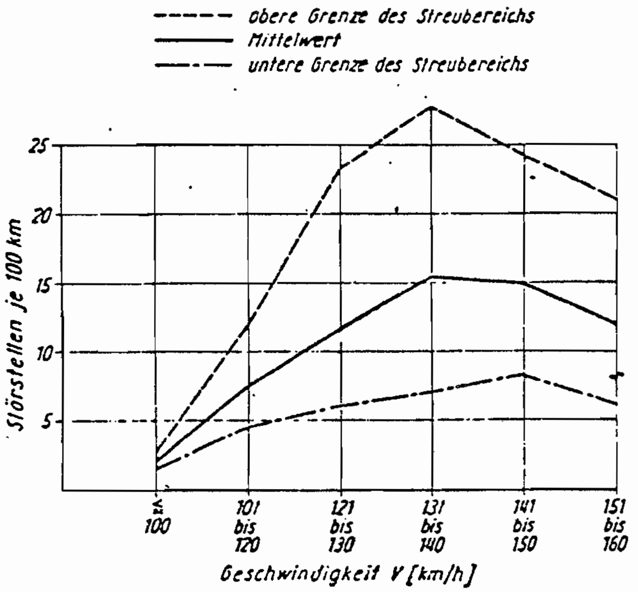
wobei 2 Q die Achskraft in kN ist, nicht überschreiten.
Es zeigt sich, daß die Achslagerquerkraft nur sehr selten allein auslösendes Kriterium ist, d. h. bei einer Überschreitung der Achslagerquerkraft werden meist auch die Beschleunigungsgrenzwerte überschritten.
Die Auslösegrenzwerte der Beschleunigungsmeßanlage und die einzuleitenden Maßnahmen - die sich nach der Höhe der Grenzwertüberschreitung richten - sind in nachstehender Übersicht dargestellt.

Zeile		Gerade		Bogen			
		b_{dyn}	F_{y3}	b_{dyn}	b_{quasi}	b_{abs}	F_{y3}
		m/s^2	kN	m/s^2	m/s^2	m/s^2	kN
1	Auslösegrenzwert	1,3	25	1,3	1,2	2,0	25
2	Unterhaltungsmaßnahmen sind einzuleiten bei	> 1,5	> 25	> 1,5	-	> 2,3	> 25
3	Geschwindigkeitsbeschränkungen sind umgehend anzuordnen bei	> 2,5	> 35	> 2,5	≥ 1,3	> 3,5	>35
4	Ausnahmen, wenn Beseitigung der Störstelle innerhalb von 5 Tagen sichergestellt wird, bei	2,5./.3,0	26./.35	2,5/.3,0	-	3,5./.4,0	-

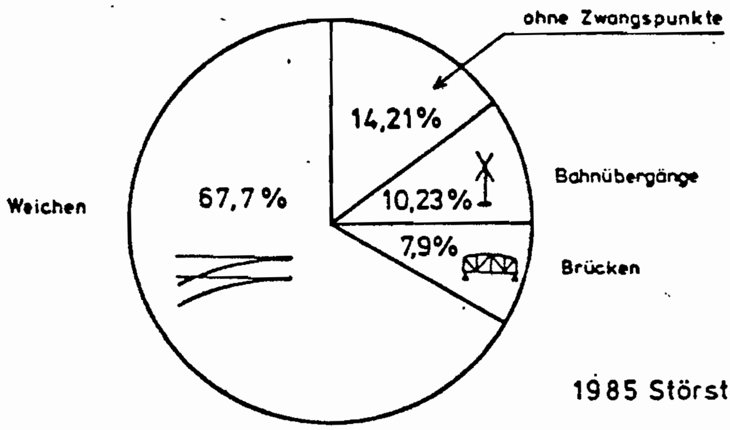
Werden die Unterhaltungsgrenzwerte nach Zeile 2 überschritten, so sind umgehend Maßnahmen zur Beseitigung des Fehlers einzuleiten. Je nach Streckenbelastung und Größe der Meßwertüberschreitung sind diese so rechtzeitig durchzuführen, daß Geschwindigkeitsermäßigungen - die nach Zeile 3 umgehend anzuordnen sind - vermieden werden. Zur Wahrung der Betriebsflüssigkeit darf ausnahmsweise auf die Einrichtung einer Langsamfahrstelle verzichtet werden, wenn diese Überschreitungen nur geringfügig sind (siehe Zeile 4).

4 - Erfahrungen aus den Beschleunigungsmessungen

Die Beschleunigungsmessungen lassen die Auswirkungen von Gleislagefehlern auf die Laufruhe unmittelbar erkennen, so daß der Oberbaudienst in der Lage ist, mit geringem Aufwand den Gleiszustand spürbar zu verbessern.
Während bei Geschwindigkeiten bis zu etwa 120 km/h die bisherige Praxis der Überwachung der Gleisgeometrie ausreichte, muß bei höheren Geschwindigkeiten eine häufigere, objektive Kontrolle durch Beschleunigungs- und Kraftmessungen durchgeführt werden.
Um die Zulässigkeit einer bestimmten Fahrgeschwindigkeit festzustellen, ist u. E. die Festlegung von gleisgeometrischen "Betriebstoleranzen" nicht geeignet. Der Sicherheitsnachweis für schnellbefahrene Gleise ist primär durch Messung der Fahrzeugreaktionen bei Fahrt mit zulässiger Höchstgeschwindigkeit zu erbringen. Um jedoch im Schnellfahrbereich, wie auch in niedrigeren Geschwindigkeitsbereichen, eine objektiv befriedigende Gleislage zu gewährleisten, müssen vorgegebene "Unterhaltungs-Richtwerte" eingehalten werden. Die "Unterhaltungs-Richtwerte" sind für die einzelnen geometrischen Parameter festgelegt, die von den vorhandenen Gleismeßfahrzeugen erfaßt werden.
Die Anzahl der Störstellen je 100 km Gleislänge, aufgegliedert in die verschiedenen Geschwindigkeitsbereiche, zeigt folgendes Bild:

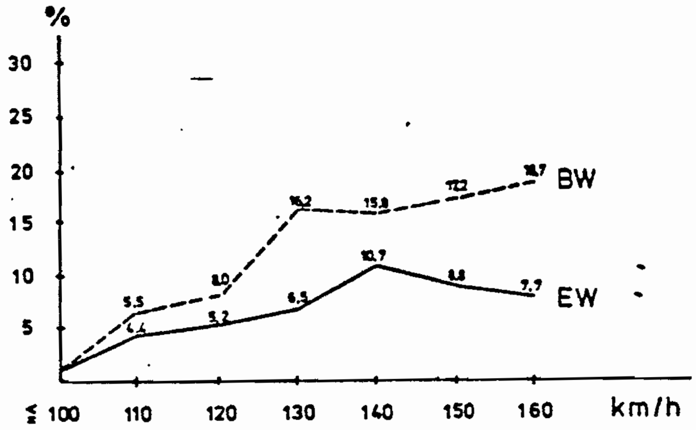


Der größte Anteil der Störstellen (knapp 90 %) wird durch Zwangspunkte in der Linienführung verursacht. Hierbei stellen die Weichen, wie nachstehende Übersicht zeigt, den größten Anteil.



1985 Störstellen

Ein Vergleich der Störstellen in Weichen zeigt, daß bei Geschwindigkeiten bis zu 120 km/h die Störungsanfälligkeit der Bogenweichen und der garden Weichen nahezu gleich ist. Im höheren Geschwindigkeitsbereich (V ≧ 130 km/h) steigt die Störungsanfälligkeit der Bogenweichen stark an (siehe nachstehendes Bild). Besonders zu Gleislagefehlern neigen Abschnitte, in denen mehrere Weichen, gerade Weichen oder Bogenweichen hintereinander liegen; dies gilt verstärkt, wenn auch die Zweiggleise stark belastet sind.



Für die Zukunft wird angestrebt, Beschleunigungsmessungen und Messungen der Gleisgeometrie zu verbinden. Hierfür ist jedoch Voraussetzung, daß der Gleismeßwagen die Geometrie bei Fahrt mit zulässiger Höchstgeschwindigkeit auf der Strecke erfassen kann.

ATTACHMENT 7

BZA München
Dr.-Ing. Oberweiler, Dez 86

Concept of a track recording car for higher speeds

1. Introduction

As mentioned before, with the acceleration measurement car of DB we measure the following vehicle reactions:

- accelerations occurring in the car body
- the transverse forces in the axle-bearing

With these measurements it is possible to detect errors in track alignment (interference points) and to gain information on the effects of the riding properties on the passengers. Along with this "interference point approach" and for evaluation of the correct position of tracks and turnouts we also detect their "Geometry" with the aid of the so-called "Track and Permanent-Way-Recording Car".

cable

2. Generallities on the track recording car, presently used by DB

This is a converted passenger coach, year of construction 1955, with a length of 26,4 m, which is used as recording car since 1964. By means of a rope, the measurement values are transmitted directly from the rails to the recording facility by means of sensors. Transmission from the axles of the 3-axle measuring bogie is purely mechanic.

For the electronic recording and processing of the measuring date, however, we need an electric transmission system. Because the vehicle will be taken out of operation for reasons of age in a few years time, an expensive convertion of this vehicle is out of the question, the more so, because new limits would be reached very soon. Furthermore, this recording car could not be used during the time of conversion.

These test runs can be carried out only at speeds up to 90 km/h, leading to the fact, that the operational implementation can be carried out only in form of special runs.

3. Measuring values to be detected

a) Gauge (1435 mm)

Presently, the gauge is being detected by sensors, sliding along the gauge face corner of the rail, against which they are pressed by a tensioning spring. Measurements give information on the condition of the rail fastening and on the lateral wear of the rail. Rolling laps at the gauge face corner can lead to a narrowing of the gauge.

Profile

b) Longitudinal level

The longitudinal level is the vertical position of the rail, measured on its running surface.

This provides information on poor welding joints, poor tamping and resilient subgrade.

Cross level

c) Transverse level

This is the mutual level of both rails, which we call superelevation in a curve. Straight or rounded ramps are accurately detected and recorded in a clear manner.

A steady line of transverse level indicates a firmly tamped track, whereas anirregular line of transverse level indicates an alternately resilient track.

d) Versine (curvature)

This is the distance between a chord positioned at the rail and its gauge face corner.

It provides information on the value of the curvature radius and indicates faults in the continuity of curvature.

e) Twisting

It represents the declivity of one rail in relation to that of the other.

It is important to know the value of this, because the vehicles (car bodies) can stand only a relatively small degree of twisting. By load transfer of diagonally positioned wheels there is the risk that guidance may no longer be maintained.

f) Of further interest are:
- the change in twist
- the alignment
- ripples and corrugations

4. Development of the new track measuring car

Already in the Fiftie's it was planned to develop a non-contact measuring technique on the basis of capacitors, corresponding to an instrument which is used for measuring road surfaces. Because the control facility of the measurement areal used in this case was too inert, this technique was no longer persued.

Also, experiments with an inductive measurement procedure which, at first, seemed promising, were discontinued, because development would have required considerable time. However, the measuring car used before the second world war had to be replaced as soon as possible. Therefore it was decided to use the proven mechanical measuring facilities in the design of the vehicle presently in use.

In this connection it is interesting, that at the beginning we envisaged also the acoustic detection of loose rail fastenings.

Only in the year of 1973 we came back to the concept of non-contact measuring techniques, and a short time ago development work was resumed.

4.1 General requirements

The recording car and the measuring systems shall be designed for a maximum speed of 300 km/h. The running and braking properties must allow the integration into all train-consists of ordinary public traffic with speeds up to 200 km/h.

Furthermore, measuring systems must no longer be subject to system-inherent errors, as is the case with the 3-point-travelling-chord-system. Distortion of measured values caused by the running of the wheel-set must also be excluded in the future.

4.2 Non-contact detection, transmission and processing of the measured values.

For the purpose of measuring the gauge aboard the recording vehicle running at high speed development work is carried out on a optical-electrical procedure. In this case, the inner gauge face of the rail 14 mm below the running surface is illuminated by a concentrated light spot (Laser) having a diameter of 1 - 1,5 mm. In order to exclude the influences of the wheel-set running this light is emanated horizontally so that the level of the spot varies only ± 1,5 mm.

This travelling light spot which is applied to the inner face of the rail is being detected by two cameras, the optical apertures of which are swept with laminar flowing compressed air to prevent contamination.

Ligh source and cameras are fixed to the car body to protect them against acceleration shocks.

The measuring accuracy aimed at is ± 0,5 mm. This system has already been tested with success up to 100 km/h on a line rich in curvatures.

Other measurement values are to be detected by means of a sliding non-contact air-cushion-sensor in capacitive or inductive manner. By means of an inductive distance meter this air-cushion-sensor is attached to the car floor. There, the acceleration is measured and is integrated two times in order to determine the distance.

As reference system and for vertical reference, a gyroscopic platform is provided, as is used for instance aboard of high-speed boats and submarines.

The measuring values will be processed completely automatically.

It must be possible to identify a transgression of limit values that is, a critical deviation of the track-geometry from its ideal condition, not only from the recordings and their evaluation, but also as a color marking for better retrieving in the track.

5. The concept of the permanent way measuring unit

Along with the measuring vehicle for the recording of track-geometry we just described, we are actually developing also a new acceleration measuring car (standard vehicle). It will be taken into operation towards the end of 1978, and after geometry-vehicle has become operational (1981) the two vehicles will be used together as one unit.

The new permanent-way measuring unit can be regarded as starting basis for the concept of an objective and automatic assessment procedure of the permanent way, with the aim of:

a) a better utilization of the financial funds for permanent-way maintenance, and

b) developing maintenance planning for the permanent way service based on objective criteria.

Trip Report
Federal Railroad Administration
&
Unified Industries, Incorporated
Visit to Sweden and Japan to Initiate IPEEP Participation Procedures

February 28 to March 12, 1977

Prepared for

DEPARTMENT OF TRANSPORTATION

FEDERAL RAILROAD ADMINISTRATION

Office of Research and Development

Washington, D.C. 20590

Under Letter Contract DOT-FR-74249

Trip Report
Federal Railroad Administration
&
Unified Industries, Incorporated
Visit to Sweden and Japan for IPEEP
February 28 to March 12, 1977

1.0 Introduction

As a part of the FRA Improved Passenger Equipment Evaluation Program (IPEEP), Swedish State Railways' and Japanese National Railways' equipment were selected as initial candidates for preliminary equipment evaluations.

The purpose of the trip was to visit Swedish State Railways (Statens Järnvagar, or SJ) and Japanese National Railways (JNR) to discuss and work out the evaluation plan and implementing procedures related to equipment of advanced design. The manufacturers of representative advanced equipment, typified by ASEA in Sweden and Tokyu Car in Japan, were also visited.

1.1 Delegation

The U.S. delegation consisted of six members. Their names and titles are as follows:

Mr. Myles B. Mitchell, Director
Office of Passenger Systems, FRA

Mr. Herbert E. Long, Executive Vice President
Unified Industries, Incorporated

Mr. Arthur T. Surkamp, Program Manager, IPEEP
Unified Industries, Incorporated

Mr. John A. Bachman, Technical Coordinator, IPEEP
Unified Industries, Incorporated

Mr. Joseph J. Schmidt
Assistant Vice President, Equipment
National Railroad Passenger Corporation (Amtrak)

Mrs. Keiko Nishimoto, Interpreter*
Unified Industries, Incorporated

1.2 Agenda

1.2.1 Sweden. Discuss status of the prototype X15 tilt-body train with ASEA and SJ with respect to potential IPEEP evaluation and testing. Discuss the development of thyristor locomotives and vehicle dynamics. Inspect maintenance facilities, ride the Rc4 locomotive, and inspect fabrication of the prototype X15.

1.2.2 Japan. Assess JNR's interest in participating in the IPEEP, and discuss the possibility of conducting a test program on the prototype 961 trainset.

Other objectives were to ride both existing bullet trains (Hikari and Kodama), a tilt or pendulum car train (Furikodensha), and the prototype 961 if possible. Visits to rolling stock manufacturers and JNR's maintenance shops were also on the agenda.

1.3 Itinerary

1.3.1 Sweden

February 27, Sunday

1445	Arrive Stockholm
1700	Review itinerary with ASEA representative

February 28, Monday

0800 - 1000	Travel by car to Västerås
1000 - 1200	Technical discussions on Thyristor locomotives, ASEA
1200 - 1430	Reception and lunch hosted by Mr. T. Lindstrom, President, ASEA

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* Japan only.

1500 - 1700	Presentation of IPEEP program

March 1, Tuesday

0830 - 1000	Presentation on vehicle dynamics, ASEA
1000 - 1030	Coffee
1030 - 1145	General discussions on IPEEP
1145 - 1245	Lunch
1245 - 1530	Travel by car to Tillberga to inspect X15 train
1530 - 1600	X15 discussions with ASEA
1612 - 1730	Travel by train to Stockholm

March 2, Wednesday

0900 - 1200	Technical presentations by Swedish State Railways (SJ) on traffic, X15, and track maintenance. Meeting chaired by Mr. Sigurd Granebeck, Director of Administrative Secretariat, SJ
1200 - 1330	Lunch
1330 - 1700	Briefing on ATC equipment and ATC simulator demonstration at Vällingby

March 3, Thursday

0900 - 1200	Inspection of SJ Maintenance Shop at Älvsjö, and inspection of SJ Locomotive and Passenger Car Depot at Hagalund
1200 - 1300	Lunch
1300 - 1700	Ride Rc4 locomotive to Uppsala, return to Stockholm by train

March 4, Friday	
0830	Depart Stockholm for Tokyo

1.3.2 Japan

March 6, Sunday	
1430	Arrive in Tokyo (PA 002)
1600	Brief meeting at Palace Hotel to finalize the itinerary with JNR representatives
March 7, Monday	
0930 - 1430	Meeting and discussion at JNR
1430 - 1600	Visit Shinkansen General Control Center
1800 - 2000	Welcoming reception given by Dr. M. Takiyama
March 8, Tuesday	
0735	Leave hotel and take train to Kanazawa Hakkei
0930 - 1130	Visit Tokyu Car Corporation
1400	Leave Tokyo by train Hikari
2101	Arrive at Hakata, Kyushu
2115	Settle in Station Plaza Hotel
March 9, Wednesday	
0930 - 1200	Visit Jakata Railcar Maintenance Center
1230 - 1400	Lunch hosted by Mr. Y. Takatori, Manager of Hakata Railcar Maintenance Center
1424	Leave Hakata by train Hikari
1803	Arrive at Shin Osaka
1830	Settle in Shin Hankyu Hotel
March 10, Thursday	
0830	Leave hotel by car for Ibaraki

0930 - 1130	Visit Osaka Railcar Operating and Repair Depot
1222	Leave Shin Osaka by General Inspection Train
1329	Arrive at Nagoya
1340	Lunch hosted by Mr. M. Kitahara, Sr. Deputy Director, International Department
1500	Leave Nagoya by pendulum car train Furikodensha Shinano
1639	Arrive Kiso Fukushima
1742	Leave Kiso Fukushima
1920	Arrive at Nagoya
1930	Settle in Nagoya Terminal Hotel

March 11, Friday

0900	Leave hotel
0924	Leave Nagoya by train Kodama
1012	Arrive at Hamamatsu
1030 - 1230	Visit Hamamatsu Workshop
1230	Lunch hosted by Mr. S. Katayama, Director of Rolling Stock and Mechanical Engineering Department
1448	Leave Hamamatsu by train Kodama
1652	Arrive in Tokyo
1830 - 2000	Farewell reception given by Japanese National Railways and Japan Association of Rolling Stock Industries

March 12, Saturday

0930 - 1200	Meeting and discussion at JNR

March 13, Sunday

2130	Depart Tokyo (NW 010)

2.0 Meeting Highlights, Sweden

2.1 February 28, Monday

2.1.1 Opening Session of ASEA

Mr. Åke Nilsson, General Manager of ASEA's Transport Division, provided a general introduction to the company and its product lines. ASEA (Allmanna Svenska Electriska Aktiebalaget) produces electric traction equipment for the Swedish State Railways, and assembles the Rc series electric locomotives. The company also produces electric rapid transit and commuter trains.

Mr. Tore Nordin, Chief Engineer, Traction Engineering Department, traced the history of electric locomotive development at ASEA. Units with fully suspended traction motors have been available since 1955. In 1957, the first 7,000 hp C-C locomotive was built for Norway. Silicon rectified B-B locomotives were introduced in 1960. Work on a 220 kph (137 mph) tilt-body train was started in 1970. Mr. Nordin's presentation was followed by a film, "Thyristor Locomotives from ASEA."

2.1.2 General Discussion Period

Mr. Mitchell presented the background and objectives of the Improved Passenger Equipment Evaluation Program. The relationships between FRA OR&D, the NEC Improvement Project Office, Amtrak, and Unified Industries, Incorporated were outlined. ASEA then exhibited a film "ASEA in Mass Transit." The film summarized electric rail cars built for use on subway and suburban lines.

2.2 March 1, Tuesday

2.2.1 Vehicle Dynamics Session

Messrs. Henry Halldin, Lage Marcusson, and Evert Andersson of the Mechanical Design Office presented design objectives and criteria for the X15. Analytical techniques for the evaluation of stresses and body elasticity were reviewed. Instrumentation techniques used for measurement of vehicle and suspension dynamics aboard prototype and test trains were also covered.

Design criteria for the X15 high speed train call for comfort levels that are the same or better than the best cars presently in operation, and at present speeds. Safety against derailment (both rail climbing and rail overturning) must be provided for conditions below the critical point. Track forces must be less (or not higher than) for present trains at present speeds.

2.2.2 General Discussions, IPEEP

A list of data and test requirements concerning the X15 trainset were presented by UII (appendix A). ASEA representatives indicated that they would have no problem furnishing data; each subject was discussed (appendix B). The X15 test schedule was discussed and the program was expected to last from April to July; there was a possibility that test operations might still be underway as late as October. Observation of and participation in the X15 tests in Sweden by IPEEP representatives appears feasible. ASEA's license relationship with GM's EMD is limited to the Rc4 thyristor locomotive only. ASEA is willing to sell know-how (license) on X15 related technology.

2.2.3 X15 and Facility Inspections

The X15 trainset is being modified at the SJ coach shops at Tillberga. The prototype train is based on the conversion of existing car bodies to which newer design active (tilting) suspension systems and trucks are being added.

Following a lengthy and detailed inspection, the party moved by auto to ASEA's new locomotive assembly plant. The locomotive plant is nearing completion and the assembly of the first Rc4 locomotives should be underway by early summer. The IPEEP team then returned to Stockholm by train.

2.3 March 2, Wednesday

2.3.1 Conference with SJ

Mr. Sigurd Granebeck, Director of the Administrative Secretariat, was host to the U.S. delegation at the SJ offices in the Centralstation, Stockholm.

Mr. P-A Dahlin, Director, Traffic Department, provided background information relative to the need for fast trains. SJ has found that it can share traffic with air transport when travel times are in the 3 to 4 hour range. SJ gains rail passenger traffic from the airlines when travel time is less than 3 hours.

Mr. T. Andersson, Chief Engineer, Rolling Stock Department, and Mr. Lars Sjöstedt, Chief Engineer, Development Department, presented SJ requirements for the X15. The X15 project began with a High Speed study in 1968, but is now referred to as the New Technology Program. It was assumed that there would be no changes in track or catenary and that all the development would center on the area of vehicle technology. A 40 to 60 percent increase in speed on curves was found to be a feasible goal.

The distribution of responsibilities between SJ and ASEA on the X15 are:

Task	Responsible Party
o Specifications	SJ
o Contract Negotiations	Both
o Preliminary performance calculations for suggested designs	ASEA
o Evaluation of performance against the specifications	SJ

Task	Responsible Party
o Hardware design and delivery	ASEA
o Hardware assembly	SJ
o Tests and evaluation	SJ (ASEA)
o Detailed performance calculations	ASEA
o Comparisons	Both
Specifications	
Computed Performance	
Observed Performance	

A presentation on track maintenance was made by Mr. G. Storm, Chief Engineer, Fixed Installations. Four categories of track standard conditions are used by SJ; they run from K0 (best) to K3 (worst). Track standard K2 is roughly comparable to Class 5 in the United States, although not quite as good. Track standard K0 is continuously welded rail with concrete sleepers.

2.3.2 Briefings on Automatic Train Control Equipment

Mr. S. Lundgren, Chief Engineer of SJ's Signalling Department, arranged a presentation on ATC equipment at the supplier's (Standard Radio & Telefon AB) facility in Vällingby. This was followed by a demonstration of a simulator run of the cab signaling system connected to the ATC center.

2.4 March 3, Thursday

2.4.1 Mr. Sigurd Granebeck escorted the group on a tour of the SJ maintenance shops at Älvsjö. These shops inspect, service, and repair EMU commuter cars. The shops are new; they offer excellent undercar access, lighting, and tool access.

The group then boarded a train for Hagalund to visit SJ's locomotive and passenger car depot. The shops at Hagalund can provide all maintenance services that are required. Their primary function is coach and locomotive overhaul; separate facilities are provided for each type unit. An automated laundry is colocated at the Hagalund facility; the laundry washes, dries, and folds all SJ dining and sleeping car linens for the entire system. The output of the mechanized laundry is impressive and the machinery is something to behold.

Mr. Granebeck then escorted the group to Uppsala aboard an Rc locomotive which pulled a consist of coaches. The cab of the Rc was clean, quiet, and comfortable. Visibility was excellent and the ride quality was good. The ATC displays (cab signals) were clear and straightforward; speed limits for the section were indicated, as was the distance to the next critical signal.

Upon arrival at Uppsala, the group awaited a return to Stockholm, arriving there about 1700. We departed Stockholm for Tokyo the next morning.

3.0 Meetings Highlights, Japan

3.1 March 7, Monday

3.1.1 Opening Session at JNR

Dr. Mamoru Takiyama, Vice President, Engineering, gave a welcoming speech that was reciprocated by Mr. Mitchell. Japanese counterparts were introduced. They were as follows:

Mr. Norio Tejima, Director
International Department

Mr. Masumi Kitahara, Sr. Deputy Director
International Department

Mr. Tetsuo Akutagawa, Deputy Director
International Department

Mr. Y. Ban, Director
Technical Development Department

Mr. M. Ishiyama, Director
Technical Development Department

Mr. Seikei Katayama, Director
Rolling Stock and Mechanical Engineering Department

Mr. M. Kato, Deputy Director
Rolling Stock and Mechanical Engineering Department

Mr. Takashi Shima, Deputy Director
Rolling Stock Design Office

Mr. Hitoshi Inone, Deputy Director
Rolling Stock Design Office

Mr. Naoharu Fukuzaki, Executive Director
The Japanese Railway Technical Service

3.1.2 General Meeting and Discussion

Mr. S. Katayama gave a general description of the Shinkansen (new corridor) train. Discussion concentrated on the major characteristics of the six-car prototype 961 electric railcar multiple unit train and compared it to the two-car experimental 951 series train. The prototype 961 was produced in 1973 and will be used for running tests to develop a newer prototype for the actual rolling stock for the Tohoku and Joetsu Shinkansen scheduled to open in March 1981. These lines are in the snowy northern area and have long stretches of steep gradients and tunnels; distance between stations is rather short compared with the New Tokaido and Sanyo Shinkansen. To meet these conditions, the prototype 961 has the following features:

o Cold proof, snow proof structure with all undercar electric equipment fully covered.

o Capacity of the traction motors raised from 185 to 275 kW (2,200 kW per 2-car unit), and correspondingly, the capacities of the main transformer (1,650 kVa to 330 kVa) and main rectifier enlarged.

o To enable through-operation over lines of different frequencies (50 and 60 Hz), the prototype 961 was designed to be a dual frequency train (e.g., 60 Hz auxiliary equipment is driven by motor alternators).

o Tare weight is lower for operation at the maximum speed of 162 mph (260 kph).

o Consideration is given to environmental protection, such as the design to abate noise and use of silicon oil for insulation of the main transformer to prevent BCP pollution.

Mr. Katayama's briefing was following by the U.S. team's presentation of the evaluation program, IPEEP. Mr. Mitchell explained the background of the program and the IPEEP questionnaire was presented to the Japanese team. Questions and answers were discussed on the program itself as well as technical matters. The Japanese were particularly interested in ensuring that testing could be done in Japan during the second phase of the program. This would alleviate the interruption of JNR's test program, and the trainset could then be shipped to the United States for further testing. Additional discussions were scheduled for Saturday morning.

3.1.3 Visit to Shinkansen General Control Center

Mr. N. Kimura, Deputy General Manager, Shinkansen Administration, gave us a briefing on Centralized Traffic Control (CTC), Automatic Train Control (ATC) system, and Computer-Aided Traffic Control System (Comtrac). Eight types of dispatchers work in the center. They are train dispatchers, electric car dispatchers, tele-communication dispatchers, signal dispatchers, maintenance dispatchers, passenger service dispatchers, electric power dispatchers, and Comtrac dispatchers. The control room is equipped with a large indication panel that shows the positions (and identification) of all trains operating within the main line control section.

3.2 March 8, Tuesday

3.2.1 Visit to Tokyu Car Corporation

The Tokyu Car Corporation was visited in the morning. A general meeting was held in the corporate meeting room prior to the plant inspection. Corporate members who attended the meeting were as follows:

Toshiji Yoshitsugu, Chairman
Ihaho Takahashi, President
I. Kato, Executive Vice President
H. Yamagishi, Senior Managing Director
M. Uchimura, Director
S. Toki, Director
S. Takeda, Engineer
Y. Tawaragi, Engineer

Tokyu Car Corporation is one of five car manufacturers who supply JNR's rolling stock. After a slide presentation, a plant tour was conducted so that we could see the manufacturing and assembly process of Shinkansen bullet trains.

3.2.2 Shinkansen Train Ride to Hakata

Returning to Tokyo after lunch, we took a limited express train (Hikari) to Hakata, Kyushu, for a distance of 731 miles (1176.5 km). The scheduled trip was 7 hours with intermediate stops at Nagoya, Kyoto, Shin Osaka, Okayama, and Hiroshima; maximum speed was 135 mph. Shinkansen was first opened between Tokyo and Shin Osaka (New Tokaido Line) in 1964, followed by the section between Shin Osaka and Okayama in 1972. It was further extended to Hakata, Kyushu, through the undersea Kanmon Tunnel in 1975 (New Sanyo Line).

Hikari is a multiple unit, electric train consisting of 16 cars (8 units). Some improvements and modifications were made for the New Sanyo Line at the extension from Osaka to Hakata such as:

o Improvements in service - automatic doors, dining car in addition to buffet car, facilities for the handicapped

o Smaller windows for less maintenance cost.

o Traction supply system changed from 25 kV, 60 Hz single phase booster transformer to auto transformer

o Power receiving system changed from 154 kV or 77 kV 2 lines, to 275 kV.

3.3.0 March 9, Wednesday

3.3.1 Visit to Hakata Railcar Maintenance Center

This maintenance shop was established as the Shinkansen workshop in 1974. Three types of car inspections are performed at Hakata: trip (daily), regular (monthly), and truck and general (overhaul) inspections. The general inspection involves disassembly, inspection, and replacement of all train systems. The Hakata shop also has a function as an operations depot with 10 tracks (to be increased to 27 in the future) for overnight storage of railcars. The inspection and repair capacity of Hakata Base is as follows:

Daily inspection	16 to 20 trains per day
Monthly inspection	2 trains per day
Truck inspection	4 cars per day
Overhaul	500 cars per year

Mr. Y. Takatori, manager of the center, was absent because of a labor dispute; in his place, three technical assistants, Messrs. Kosuke Ishii, Keiji Okada, and Yu Yamamoto described the facility and conducted the tour.

3.4.0 March 10, Thursday

3.4.1 Visit to Osaka Railcar Operating and Repair Depot in Iboraki

The prototype 961 is kept at this depot. It bears a superficial resemblance to the Hikari or Kodama trains, but has a longer skirt. The prototype 961 is a consist of six cars: three standard cars, one dining car, one sleeping car, and one ride quality measurement car (variable stiffness for testing the relationship between suspension stiffness and ride comfort). With the courtesy of Mr. H. Kawai, chief of the depot, we rode the prototype train through the coach yard at a very low speed.

3.4.2 Ride on General Inspection Train

We left Shin Osaka aboard a General Inspection Train which runs at the revenue speed of 130 mph (210 kph). It is a comprehensive inspection train, capable of inspecting and recording measurements of both electric traction equipment and track conditions. It employs the latest on-board measurement devices and produces oscillograph charts of measured parameters. The train consists of the following cars:

Car Number 1: Measurement of communication, signal, electric conversion, and overhead electric systems.

Car Number 2: Measurement of electric power supply system, observation of the pantograph, and automatic data processing.

Car Number 3: Electric traction supply feed and data processing.

Car Number 4: Electric energy feed and rest room for the staff.

Car Number 5: Measurement of track conditions and data processing.

Car Number 6: Storage of relief pieces and materials and observation of the one pantograph.

Car Number 7: Measurement of electric power supply system and catenary wear.

During the 1-hour ride to Nagoya, each member of the U.S. group rode in the driver's cab.

3.4.3 Ride on Pendulum Car Train (Furiko Densha)

The tilt-body train was put into revenue service in 1973 between Nagoya and Nagano over a distance of 156 miles (252 km). Because the cars have a tilting mechanism, the speed on curves could be raised without impairing ride quality. This resulted in a 40 minute decrease in trip time relative to conventional equipment.

The group left Nagoya in the afternoon to ride a pendulum car train (Shinano). The travel time was about 1 hour and 40 minutes to Kiso Fukushima in the Japanese Alps on the Chuo Line (narrow gage); the return trip was made an hour later. The pendulous motion was smooth and well damped; it is locked out at speeds below about 19 mph (30 kph).

3.5.0 March 11, Friday

3.5.1 Visit to Hamamatsu Workshop

This workshop is very old compared to the Hakata maintenance center. It was founded in 1912 to repair steam locomotives serving the Tokaido Main Line and its several branch lines. In 1965, the shop started to perform general inspections of the Shinkansen EMU cars and to date has overhauled 7,000 cars. Mr. Kazuo Jimbo, manager of the workshop, briefed us with a film presentation to provide an overall idea of how the general inspection is carried out. The term general inspection is a misnomer by U.S. standards. The total process includes in-shop inspection, disassembly, body repair, painting, assembly adjustment, testing, consist testing, and trial running. It takes 10 days for a train to go through the complete cycle. The carbody is dismounted on the first day after visual shop inspection and preparation, and the equipment is disassembled for a thorough inspection and repair. This general overhaul is given after 900,000 km (559,300 miles) or 30 months for all Shinkansen trains.

3.6.0 March 12, Saturday

3.6.1 Final Discussion and Meeting At JNR

A final meeting was held in the morning at JNR; the Japanese agreed upon the first phase of the program saying that the specifications on prototype 961 would be ready by early May. The questionnaire presented by the U.S. team was answered to our satisfaction (appendix C). People who attended the meeting were:

Mr. N. Tejima	International Department
Mr. M. Kitahara	
Mr. T. Akutagawa	
Mr. S. Katayama	Rolling Stock and Mechanical Engineering Department
Mr. M. Kato	
Mr. M. Ishiyama	
Mr. T. Haga	
Mr. T. Shima	Rolling Stock Design Office
Mr. T. Inoue	

APPENDIX A

Improved Passenger Equipment Evaluation Program

Questions For Potential Suppliers

A. Performance and Physical Data

Can you provide:

1. Schematics and structural drawings of the trains to be evaluated?

2. Static and dynamic clearance outlines?

3. Location of center of gravity, maximum lateral offset of center of gravity, and maximum roll angle? (This data required for both the inactive and active conditions of active suspension cars and trainsets.)

4. Continuous and short-time (5 minute or 2 minute) rating of the weakest element in the propulsion system?

5. Tractive effort vs. speed curves for the following ratings: maximum, one hour, and continuous?

6. Braking effort vs. speed and rate curves for each mode of braking employed by the test vehicle?

7. Weights of each vehicle involved in the train, as well as the axle loading?

8. Train resistance data for the subject vehicles through their entire speed range?

9. Train strength including compressive loads at centerline draft and 12 inches above centerline draft, buff load, collision post shear strength at bottom (or equivalent), and anticlimbing resistance capacity and means?

10. For propulsion systems under consideration, what is their thermal time constant? We generally define thermal time constant as the time in minutes required to bring any critical component of a propulsion system to a temperature that should not be exceeded when the propulsion system is continuously subjected to its maximum propulsive and braking tractive efforts. Temperature measurement should be made after equipment is thoroughly warmed up, e.g., after a revenue run. (Note: Regular Metroliners have a thermal time constant of 15 minutes; the Upgraded Metroliners have a thermal time constant of 30 minutes.) Experimentally, maximum tractive effort is applied by going alternately from power to brake, and a dynamic brake equal to propulsive effort is implied.

B. Test Operations

1. Is there any objection to the measurement of on-board and wayside performance and force data by the IPEEP test team? We plan to provide the

necessary test equipment.

2. What can be measured? Are there restrictions on the measurement of any test parameters?

3. It is our intention to take the data obtained in our tests to the United States for reduction and analysis. Will you accept the results of our tests on this basis?

4. Is any of the data, which will be acquired on the tests or from preliminary tests, proprietary or is it public?

5. Assuming that test data is taken by you (supplier or railroad), how will it be made available to the evaluation team?

6. What, if any, restrictions will there be for the technical personnel on riding the equipment cabs and cars in test configurations, both in this country and abroad?

7. How will track geometry be defined (to assure comparability of test data from one site and one train to others)?

8. Will translators or interpreters be available to the evaluation team?

9. Will there be any differentiation between FRA employees and consultants with regard to test data and the conduct of the tests?

C. Contractural Aspects

1. Will you accept a U.S. Government Bill of Lading as a complete transportation contract for the purpose of bringing your train to the United States? If not, what arrangement(s) would you contemplate?

2. How would you propose to let us use your train (e.g., by lease)?

3. If leased, from whom will the equipment be leased?

4. How would you support the equipment while it is in transit and in the United States? How many of your personnel would you want to send? What would be the cost?

5. Who will carry insurance for the equipment and our personnel abroad and in this country?

D. Data Categories

Questions under A, B, and C relate to information needed to begin the preliminary train evaluation. Additional information will be required for subsequent detailed evaluations, and the attached list of data categories identifies the data requirements of IPEEP.

Can you provide the data described in the attached list, and do so within 60 days?

- 1.0 Drawing Type Information Required
  - 1.1 Clearance diagram
  - 1.2 Equipment location schematic
  - 1.3 Train configurations (vehicle makeups)
    - 1.3.1 Train length
    - 1.3.2 Maximum number of passengers
  - 1.4 Description and types of cars
- 2.0 Basic Vehicle Dimensions
  - 2.1 Length over couplers
  - 2.2 Length over buffers
  - 2.3 Pantograph lockdown height (electric)
  - 2.4 Maximum pantograph running height (electric)
  - 2.5 Carbody height
  - 2.6 Distance between bogie centers
  - 2.7 Carbody width (maximum at/height)
  - 2.8 Height of carbody above rail (maximum)
  - 2.9 Average carbody width
  - 2.10 Frontal area (lead cars only)
  - 2.11 Average carbody length
  - 2.12 Truck wheel base
  - 2.13 Axle centers
  - 2.14 Minimum curvature radius
  - 2.15 Center of gravity height
  - 2.16 Maximum lateral offset of center of gravity
  - 2.17 Coupler height
  - 2.18 Platform height required
- 3.0 Static and Dynamic Weights
  - 3.1 Weight in working order
  - 3.2 Maximum weight with full passenger load
  - 3.3 Weight per axle
  - 3.4 Weight on driving axles
  - 3.5 Unsprung weight
- 4.0 Strengths
  - 4.1 Compressive loads
    - 4.1.1 At centerline draft
    - 4.1.2 Twelve inches above centerline draft
  - 4.2 Buff load
  - 4.3 Collision post shear strength at bottom connection
  - 4.4 Anticlimber capacity
  - 4.5 Structural arrangement (to check design against applicable rules and standards)
  - 4.6 Truck to carbody attachment
    - 4.6.1 Vertical
    - 4.6.2 Shear
  - 4.7 Jacking provisions
- 5.0 Performance Characteristics
  - 5.1 Maximum service speed
  - 5.2 Maximum tractive effort
  - 5.3 Continuous tractive effort (lbs. at MPH)
  - 5.4 One hour rating (HP @ MPH)
  - 5.5 Continuous rating (HP @ MPH)
  - 5.6 Adhesion limit (envelope of tractive effort vs. speed)
  - 5.7 Tractive effort vs speed (propulsion)
  - 5.8 Tractive effort vs speed (service brake)
  - 5.9 Tractive effort vs speed (emergency brake)
- 6.0 Subsystem Characteristics
  - 6.1 Propulsion (non-electric version)
    - 6.1.1 Description and schematic
    - 6.1.2 Power/weight ratio
    - 6.1.3 Anti-pollution system
      - (a) Description and schematic
    - 6.1.4 Curves of fuel comsumption vs tract effort and speed
  - 6.2 Propulsion (electric version)
    - 6.2.1 Line voltage (nominal, maximum, minimum)
    - 6.2.2 Line frequency (nominal, maximum minimum)
    - 6.2.3 Power consumption
      - (a) Line KW vs tractive effort and speed
    - 6.2.4 Description of wheel slip control
    - 6.2.5 Dynamic/regenerative
  - 6.3 Auxilliary power requirements (KW and KVA)
  - 6.4 Trucks
    - 6.4.1 Type and outline drawing
    - 6.4.2 Primary suspension
      - (a) Springs
      - (b) Damping
    - 6.4.3 Secondary suspension
      - (a) Springs
      - (b) Damping
    - 6.4.4 Axle and journal size
    - 6.4.5 Wheel diameter (maximum, minimum)
  - 6.5 Braking system
    - 6.5.1 Description and schematic
    - 6.5.2 Friction/dynamic brake blending schedule
  - 6.6 Couplers
    - 6.6.1 Type and description
    - 6.6.2 Buff and draft strength
  - 6.7 Communications
    - 6.7.1 Train radio description
    - 6.7.2 Cab signals describtion
    - 6.7.3 Public address description
  - 6.8 Train control and protection
    - 6.8.1 Description of system
    - 6.8.2 Speed control
  - 6.9 Pantograph (electric version)
    - 6.9.1 Type and description
    - 6.9.2 Maximum speed
  - 6.10 Passenger amenities and comfort
    - 6.10.1 Ride quality characteristics
      - (a) Acceleration and jerk
      - (b) Lateral and vertical forces
    - 6.10.2 Furnishings and facilities
      - (a) Seating
      - (b) Baggage
      - (c) Windows layout
        - (1) Dimensions
        - (2) Number
        - (3) Material
        - (4) Strength
      - (d) Food services
      - (e) Toilet facilities
        - (1) Number
        - (2) Location
        - (3) System description
      - (f) Handicapped facilities
      - (g) Lighting
    - 6.10.3 Environmental Control
      - (a) Heating
        - (1) Type and description
        - (2) Power requirements
      - (b) Air conditioning
        - (1) Type and description
        - (2) Power requirements
      - (c) Insulation and weather seals
        - (1) Cabin
        - (2) Doors
    - 6.10.4 Internal noise levels
      - (a) Specifications for passenger and crew compartments
      - (b) Noise insulation techniques
    - 6.10.5 Doors
      - (a) Type and location
      - (b) Description of control system
      - (c) Closing pressures
      - (d) Safety features
- 7.0 Environmental Impact
  - 7.1 Pollution levels
  - 7.2 External noise data
    - 7.2.1 Short distances
    - 7.2.2 Long distances
- 8.0 Miscellaneous
  - 8.1 Traction motor gear ratios
  - 8.2 Maximum tr. motor speed (rp

DATA CATEGORIES - IPEEP

Trip Report
Federal Railroad Administration
&
Unified Industries Incorporated
Visit to England, France, Italy, and Switzerland to Initiate IPEEP Participation
May 10 to 27, 1977

Prepared for

DEPARTMENT OF TRANSPORTATION

FEDERAL RAILROAD ADMINISTRATION

Office of Research and Development

Washington, D.C. 20590

Under Letter Contract DOT-FR-74249

TRIP REPORT

Visit to England, France, Italy, and Switzerland
May 10 to 27, 1977

1.0 Introduction

Officials of four European operating railroads and their principal suppliers were visited in May 1977 as part of the Improved Passenger Equipment Evaluation Program (IPEEP). This second overseas trip involved visits to England, France, Italy, and Switzerland to present IPEEP, discuss their potential participation, and obtain basic train information for the phase I evaluations.

1.1 Delegation

The U.S. delegation consisted of five members. Their names and titles are as follows:

Mr. Myles B. Mitchell
Director, Office of Passenger Systems, FRA

Mr. Richard A. Novotny
Chief, Passenger Equipment Division, FRA

Mr. Arthur T. Surkamp
Program Manager, IPEEP, UII

Mr. John A. Bachman
Technical Coordinator, IPEEP, UII

Mr. Joseph J. Schmidt
Assistant Vice President, Equipment, National Railroad Passenger Corporation (Amtrak)

1.2 Agenda

The agenda in each of the countries visited followed similar lines as outlined below:

a. Presentation by host rail officials on advanced rolling stock developments and plans;

b. presentation and discussion of IPEEP;

c. ride equipment of interest to observe operation and performance;

d. visit manufacturing facilities; and

e. discuss IPEEP data requirements, test programs, and contractural aspects related to potential involvement of a foreign trainset in subsequent evaluation phases of IPEEP.

1.3 Itinerary

Dates	Country	Topic
May 10, 11, 12	France	TGV-PSE at SNCF
May 13 - 17	Italy	Y0160 at FA and Fiat
May 18	Switzerland	Type III cars at SBB
May 20	France	TGV-PSE with Alsthom and SNCF
May 23 - 27	England	APTP and HST with British Rail

2.0 Meeting Highlights - France

2.1 May 10, Tuesday (SNCF)

Mr. Andre Portefaix, Deputy Director, Direction du Materiel, SNCF welcomed the U.S. delegation and introduced the principal members of the Rolling Stock Design Department. They were:

Messrs. R. Garde, Chief Engineer
J. M. Metzler, Senior Engineer
G. Petit, Engineer
G. Senac, Senior Engineer
J. Daffos, Engineer
G. Avouac, Engineer

Mr. Portefaix initiated a presentation on the new Paris Southeast line (Paris - Lyon), TGV rolling stock, and high speed research. The first two trainsets will start running tests in July 1978. Subsequent deliveries will be at the rate of three trainsets a month beginning in October 1979. The new electrified line will open for revenue service in October of 1981 with one train (TGV-PSE) every half hour in each direction during weekdays. The Friday evening peak travel demand will be met with one train every 5 minutes. A total of eighty-seven 10-car trainsets will be built to provide this level of service. Each train will carry 370 passengers; one-third will be in first class. The TGV-PSE will have simple dining facilities.

Speeds will vary from 136 to 167 mph (220 to 270 kph) depending upon track gradient on the new line. Two power cars (one at each end of the train) will supply 6300 kW to 6 BB type trucks. The power cars will have a dual current capability (e.g., 25 kV, 50 Hz, and 1500 V dc). The new line will be electrified at 25 kV, but travel beyond Lyon to the Riveria will be on older dc sections.

The turbine powered TGV.001, built 5 years ago, has accumulated about 250,000 miles in prototype testing. Over 1,000 tests have been made at speeds over 160 mph and 200 tests have been made at 185 mph. SNCF dropped development of the turbine powered version because of the fuel crisis.

The TGV.001 is a five-car, articulated, unit trainset mounted on six Y229 type two-axle bogies (trucks). Power cars, located at each end of the train, contain two gas turbines apiece. Each pair of turbines is geared to a traction alternator, which in turn supplies power to three trucks. Each axle is driven by a 310 kW traction motor mounted to the truck frame; final drive is by means of a cardan shaft. The Y229 is an H-frame, outboard journal bogie. Its axles are mounted with an Alsthom link type primary suspension utilizing new type Metalastik springs and hydraulic dampers. Sumiride bellows are used for the secondary suspension. A later version (Y2298) with coil spring secondaries, was developed and tested as the articulation carrying bogies on the TGV.001.

The TGV-PSE will also employ six powered bogies but with a different configuration. Each power car, located at the end of a 10 unit train, will be mounted on two Y230 bogies. The eight articulated intermediate cars will be mounted on seven Y231* unpowered bogies and two powered Y230 bogies; the powered bogies will be adjacent to the power cars and are not the articulated type. The Y230 resembles an unpowered bogie, however, because the traction motors are mounted to the carbody and drive frame mounted gear boxes in the tripod arrangement. The Y226 bogie has been tested under the Zebulon, and served as a prototype for the Y230.

The Telma type Eddy current track brakes will not be used on the TGV-PSE because the blending of dynamic braking with the combined tread and disk brakes will be sufficient. Eddy current braking was found to overheat rails from trains running at five minute headways.

The TGV-PSE will draw power from the catenary with a two stage pantograph. This device minimizes the mass of the pantograph arm maintaining contact with the overhead wire at high speeds; it also allows a large range of motion for travel on older lines beyond Lyon. It is being tested on a BB15041 locomotive.

Phase breaks on the 25kV single phase Paris - Lyon line pose no problems for TGV operation. Current SNCF practice is to use wayside signals to indicate junction points in the national grid. The engineman reduces power to zero and brings it back up after passing under the new wire. (Only one pantograph will be used for the TGV-PSE which will trainline 25kV to the rear power car.) If the train must stop in the dead section isolating the phase differences, the engineman restores power to the dead section from a wayside controller.

Mr. Mitchell presented the background and objectives of IPEEP. The relationships between FRA OR&D, the NEC Improvement Project Office, Amtrak, and UII were explained. Mr. Surkamp followed with a description of the various tasks of IPEEP. A list of questions (appendix A) was given to SNCF. These questions concerned information required for preliminary evaluation of the TGV-PSE. Mr. Garde indicated that SNCF and its trainset supplier, Alsthom-Atlantique, would respond to the questions at a subsequent meeting on May 20. Mr. Schmidt also reviewed answers to a list of questions he had previously submitted to SNCF.

The group departed Paris from Austerlitz Station for Bordeaux by train with an intermediate stop at Saint-Pierre-des-Corps (Tours). The Paris - Bordeaux line is electrified (1500 V dc) and maintained for 125 mph (200 kph) running speeds. At Tours, Messrs. Bachman, Novotny, and Surkamp boarded the cab of the CC6500 locomotive pulling the Trans Europ Express (TEE) Aquitaine. This train made a special stop at Angouleme so that Messrs. Mitchell and Schmidt could take a turn observing operations from the locomotive cab.

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*The Y231 bogie has a slightly longer secondary coil spring (1.733 m) than the Y229B (1.242 m)

2.2 May 11, Wednesday (SNCF)

High-speed running was the main business of the day. The group met at the Bordeaux running shed adjacent to Gare St. Jean for a pit inspection of the experimental Z7001 (Zebulon) and TGV trains.

The Z7001 is a single car research vehicle currently being used expressly for truck testing at high speeds. The car was initially used to test various electrical components (including the pantograph) for TGV-electric. Traction motors are body mounted and the gear box is mounted on the truck frame and axle with a concentric final flexible drive. An inductive rail brake is used for high speeds and is blended with tread brakes at low speeds. It will not be used on the TGV-PSE.

The Z7001 was boarded for the 43-mile trip to Morcenx. Speed was kept down to 100 mph for the first 25 miles during transit to the test track; thereafter the Zebulon test car was accelerated to 185 mph on the remaining 18-mile stretch. It is difficult to attain high test speeds southbound because of the need to slow to 112 mph for a curve that is located about 8 miles from the end of the test track. The return run, north from Morcenx, allowed us to attain a speed of 193 mph (310 kph) after clearing the curve.

The prime function of the Z7001 is developmental testing of various truck designs to determine their dynamic characteristics, and to do so over a relatively wide speed range. Wheel profile, an important parameter, has been explored in terms of stability criteria for various stages of wear. SNCF emphasized that the day's high-speed runs were being made on old wheels; the wheelsets had 190,000 km logged on them at the time. SNCF normally expects 150,000 km (93,000 miles) from a set of wheels before turning them.

Upon return to Bordeaux at Gare St. Jean the group boarded the TGV.001 which had been brought into the station. We were joined there by Mr. Jean Bouley, Director, Direction du Materiel, SNCF. Passenger access is convenient through plug-type doors. Interior accommodations in second class are comfortable; two rows of two abreast seats face the center of the car. Access to the car end vestibule is through powered doors that open automatically. The first class accommodations feature a single row of seats along one side and two seats along the other side. Each seat has a novel table that is stored in the arm rest of the seat when not needed. Windows through the train contain double glazing.

The middle car of the TGV.001 contains the test equipment and instrumentation. It was during the second run of the afternoon, traveling north from Morcenx, that a speed of 302 kph (188 mph) was attained. The engineman's control layout resembles an aircraft control panel more than that of a locomotive.

Ride quality, excellent at 300 kph, was not quite as smooth at 180 kph. There appeared to be some natural body frequency vibration at that speed. Yaw, lateral, and vertical motions were well controlled and barely noticeable at all speeds. The car interiors are very quiet.

The return to Paris was aboard TEE L'Etendard. Normal running speed for this train is 180 kph. The ride was comfortable and relatively quiet.

2.3 May 12, Thursday (SNCF)

The group left the hotel at 0700 for the Paris-Est station to board a train for Chalon-sur-Marne. Purpose of the trip was to observe the 200 kph (125 mph) operation of a series BB 15000 locomotive with six coaches on the return to Paris. Members of the group alternated riding in the locomotive cab. The BB15000 locomotive operates on one of the newer electrified lines with 25 kV, 50 Hz traction supply. The locomotive is equipped with monomotors and uses a novel two-stage pantograph for high-speed running (this type pantograph will be used on the TGV-PSE). Arrangements for the demonstration, as well as the technical briefings, were provided by Mr. G. Coget, Chief Engineer, Rolling Stock Design Department, Direction du Materiel, SNCF, and Mr. F. Nouvion, Technical Director, Traction-Export Company.

Additional discussions were held at the Headquarters of SNCF's Direction du Materiel upon the return to Paris. Messrs. Bouley, Coget, and Nouvion provided additional information on the newer locomotive traction systems. The BB15000 locomotive uses solid state switching rather than mechanical switching for motor controls. The solid state control logic in the motor control system provides better reliability than cam operated tap changers. The electronic system replaced many moving parts and resulted in fewer mechanical relay actions (e.g., 40 cam actions per kilometer reduced to one per 40 kilometers of locomotive travel). Locomotive maintenance with this type system allows 3,000,000 kilometers (1,864,000 miles) between overhauls; SNCF averages 30,000 km/mo on BB series AC locomotives.

Solid state logic provides smoother acceleration characteristics which result in reduced wheel wear. Electrical transients from overloads and faults were also claimed to be less abrupt. Power factor is controlled by means of dual rectifier bridges for each traction motor (one motor per bogie). An all-thyristor bridge is used for acceleration to about 70 kph (44 mph). During acceleration the power factor improves and approaches 0.8. In the speed range from 70 to 100 kph a shift is made to the other bridge which contains a combination of diodes and thyristors. This action prevents the decline in power factor at high speed. The second bridge maintains the power factor at 0.8 throughout the cruise speed range to 160 kph (100 mph).

Each monomotor works separately allowing the maximum use of locomotive weight for traction. One benefit is extended wheel life. The BB15000 series locomotives have a wheel life of 1.5 million kilometers (930,000 miles); this compares favorably with the BB16000 series locomotives equipped with ignitrons or silicon rectifiers. Both locomotives operate from a 25kV single phase supply.

Regenerative braking may be used on the 25 kV lines to feed power back to the national grid. The BB1500 locomotive equipped with auto-thyristor controls has this capability. It is not feasible on the dual current (ac - dc) locomotives or light-weight trains such as the TGV.

The BB15041 locomotive used for the trip from Chalons-sur-Marne demonstrated regenerative braking for service stops. Tread braking, blended for the final stopping and parking mode, also provides tread cleaning functions. SNCF regenerative braking requires stabilizing resistors which double as dynamic brake loads for emergency braking. Their design approach is that regeneration cannot be relied on for absolute safety in the event of supply network failures.

Regenerative braking has been used for five years and the first BB16500 series locomotives with regenerative braking were ordered in 1960. There have been no complaints from commercial utilities with respect to power factor, single phase load unbalance, or distorted waveforms resulting from regenerative locomotive braking on intercity lines. This is not the case with suburban systems where the number of cars and their density in urban areas is high. While regenerative braking systems are not used aboard the majority of the commuter fleet (older cars), considerable attention must be paid to these parameters in the future as the fleet mix changes.

Upon completion of the conference with SNCF, the group boarded the international express "Palatino" for the overnight journey to Rome. Ride quality was poor with exceptional lateral motion of the sleeping car. Food service was far beneath that experienced on TEE trains; one car provided an inadequate supply of food in automat style.

3.0 Meeting Highlights - Italy

3.1 May 13, Friday (FIAT)

The visit to Rome was necessary to observe operation of the FIAT built ETR401 four-car electric multiple unit (EMU) trainset. It is in revenue demonstration service between Rome and Ancona operating under the name "Pendolino." A briefing and walk around inspection of the ETR401 was conducted by Messrs. Santanèro (Chief Engineer, FIAT Railway Division), and Guido Foggini (President, FIAT U.S. Representative, Inc.).

Entrance to the train is convenient because of the large doors, accessible steps, and low floor level. The train uses automatic couplers rather than the usual hook and chain that is common in Europe. The cars ride on "Y" type trucks and employ magnetic track brakes in addition to blended dynamic and pneumatic disk brakes. The inboard axles are powered by body-mounted traction motors. The engineman rides well forward in a compartment about the size of the Metroliner's.

The ride was relatively rough the first 30 minutes because of track alignment. Lateral motions were bad on bad track but the vertical motions were relatively good. Ride quality was good in the mountains, interior noise was low, and the tilting motion in curves was quick but steady. The interior is styled much like that of an aircraft. The train is quiet and the hydraulic pumps could be heard apparently restoring pressure after the car-body had begun its tilting movement.

3.2 May 15, Sunday

The IPEEP delegation boarded TEE Vesuvio for the trip from Rome to Florence along the direttissima. Mr. Schmidt of Amtrak returned to the United States.

The new line, or direttissima, between Rome and Florence will allow train speeds of 250 kph (155 mph) when completed. Twenty-five miles have been eliminated from the old route by four cut-offs. Not all of the upgrading is complete, but those sections that have been finished offer excellent examples of premium roadbed construction. The Italian State Railway has built a "superhighway" upon which ballast, ties, and rails have been laid with great precision in profile and alignment.

3.3 May 16, Monday (FS)

The Material and Traction Department of Ferrovie Dello Stato (FS), or the Italian State Railways, is located in Florence. Representing FS at the morning meeting was Professor Paolo Camposano, Department Manager, and Messrs. Cardini and Bernini of the Traction Department. Mr. Guido Foggini of FIAT and Mr. Rene Baronnet of Battelle-Geneva were present to provide technical interpretation.

Mr. Mitchell presented IPEEP and its relationship with the NEC Office and Amtrak. Mr. Surkamp reviewed UII's role, the three phases of the program, and the interrelationships of the five tasks. The list of questions for potential suppliers (appendix A) was reviewed and a response was provided by FS to each question (appendix B). In general, the questions posed no problems. FS prefers testing in Italy on our behalf and can supply needed equipment.

Additional discussion centered on FS plans for development of rolling stock and right-of-way. The Pendolino has been put into service on the mountainous Rome - Ancona line. FS had planned to use six on the Rome - Florence direttissima. Because of the lack of funds after the 1974 recession, the program was shelved. No further development of the Pendolino program is expected soon. FS currently has locomotives and cars capable of providing 200 kph (125 mph) service.

It was learned that the E.444 locomotive, rated at 4020 hp (3000 V dc), utilizes chopper motor controls. FS is preparing a BB locomotive for 250 kph (155 mph) service, and is studying the implications of 23-ton axle loads. Other plans include the utilization of body-mounted traction motors on BB locomotives. It was noted that the mechanical problems involved in weight reduction are more difficult to solve than the electrical problems.

The IPEEP team, impressed with the quality of service offered by TEE trains, asked about future plans. New TEE cars are needed for 200 kph (125 mph) speeds; they would need new brakes (e.g., electromagnetic) for service at that speed in Italy. TEE specifications for passenger comfort are quite rigid.

Other new rolling stock requirements concern new day service trains for use within Italy. The cars would be made of light-weight steel and have a gross empty weight of 66,000 pounds for service at 180 kph (112 mph).

In other areas, new work is focused on the following goals.

a. Track improvements and the completion of the Rome - Florence line. A new high-speed track network is part of an overall European plan. The Rome-Florence line will be a segment of the future high-speed Naples - Milan line.

b. Electrification. It is important to finish the electrification of the FS network. Catenary must be strengthened and new or remodeled substations are needed to serve heavier and faster trains. One old three-phase line must be converted to 3000 V dc.

c. Current collection. FS is working on the problem of current collection at high speed and high power. ORE is establishing standards for 250 kph service.

d. Signaling. Automatic signaling and coded track circuit cab signaling installations will be expanded throughout the network.

FS is not working on the development of an Eddy current brake. Work is being done on the development of three-phase traction motors. Inverters will be used to supply the ac motors from the dc source. The ac system is being studied for application to locomotives, although a specific type has not been selected. Current effort is the construction of a shunter (switch engine); final application may be a BBB articulated locomotive.

3.4 May 17, Tuesday (FIAT)

Dr. Ing. Renato Piccoli of the FIAT SPA Rolling Stock Division welcomed the IPEEP group to the division headquarters in Turin, Italy. Also present at the meeting were Messrs. Santanero (Technical Department Manager), Delamorte (Technical Department), Foggini (FIAT, U.S.), and Baronnet (Battelle-Geneva).

Mr. Mitchell briefed Dr. Piccoli on the status of IPEEP and the changes that have occurred since a prior meeting a year and a half earlier. The UII role in IPEEP was presented, and the list of questions to potential suppliers was reviewed (appendix C).

Dr. Piccoli stated that the Y-0160 was built with two objectives: the development and test of a powered, or active, body tilting system; and as a means of testing wheel and rail forces for high-speed operation. The maximum amount of body tilt for the Y-0160 is 12 degrees for test purposes; this will be limited to 6 degrees in production versions. Production versions of the train could have less tilt, no tilt, or whatever is required. High-Speed operation is not required on the mountain lines; a tilting suspension is not required on the new high-speed lines.

Dr. Piccoli emphasized the need for electrification to solve petroleum-based energy problems. However, he does not think that electrification is the best solution for low traffic, long-haul lines. He expressed the opinion that the United States should look at the reorganization of its entire rail system. The United States should have an overall rail plan and a strong agency to run it. He was quite critical of the weight of E60 locomotives and Metroliner cars.

We expressed interest in reviewing specifications for the TEE trains that FIAT has built (e.g., TEE Vesuvio) and asked for copies of the specifications. Dr. Piccoli stated that they are too detailed to send to us but FIAT will provide a summary. We were invited to return for the purpose of reviewing the specifications.

4.0 Meeting Highlights - Switzerland

4.1 May 18, Wednesday (SBB)

The IPEEP group met with Dr. Hans Heinrich Weber (Chief Engineer, Rail Car Construction), Schweizerische Bundesbahnen (SBB), the Swiss Federal Railways. The purpose of the meeting with Dr. Weber was to discuss the development plans for SBB's Type III tilt body coach. A non-tilting version of the car is in service as the Swiss Express. Also present were Mr. Marti, Chief of Tests and Measurements, SBB; Mr. E. W. Bizic, First Secretary, U.S. Embassy, Bern; and Mr. Paul Reithaar, Manager Export Projects, Schweizerische Industrie-Gesellschaft (SIG).

Mr. Novotny presented IPEEP, its background, and objectives. He indicated that SBB's Type III tilt body coach is one of the equipment items under evaluation in the IPEEP. Dr. Weber suggested that we also consider a Swiss BB locomotive that has a very low ratio of lateral to vertical (L/V) wheel forces; this is a special Swiss capability.

Mr. Surkamp reviewed UII's role in IPEEP and discussed the three phases of train evaluation. Dr. Weber then reviewed SBB's test program.

SBB will complete its program of tests with four cars that use "laboratory" grade electronic components. The tests will start in October with the cars in commercial service to determine public reaction. The train will run between Bern and Lausanne in November and December at speeds 20 kph above normal speeds on curves. This line has a 140 kph (87 mph) limit with conventional equipment. (UII has subsequently learned that the tests may not begin until December.) Winter tests are scheduled for January or February in Norway (schedule changes, if any, not known). The Type III cars will probably be available for revenue service in the summer of 1978.

Dr. Weber indicated that adhesion limits are higher in the summer (in Switzerland) so a full "overspeed" capability is not recommended because of the higher lateral forces to the rail. Locomotive axle loads are 20 metric tons (44,000 pounds), and SBB has modified the locomotive to be used with the four type III cars by installing an actuator sensor for the first coach (the locomotive does not tilt).

SBB uses instrumented wheels to obtain lateral forces; strain gages are attached to the wheel spokes. (For more information, refer to Report R-14 of ORE Technical Committee B-10.) He added that British Rail has used this method as has JNR and SNCF. UIC's Office of Research and Experiments (ORE) lists other techniques such as those of the German Federal Railways and Sweden's SJ. SBB criteria for derailment is a Y/Q (e.g., L/V)=0.8, and for normal running Y/Q should not exceed 0.6.

In response to Mr. Mitchell's question on the availability of an instrumented wheelset, Dr. Weber replied it would take from 6 to 9 months to deliver one. He stated that it took eight years to develop the technique they are presently using.

In response to questions on SBB development activities related to propulsion, Dr. Weber stated that the development of three phase traction motors was begun in 1962. Brown-Bovari Company (BBC) has built six diesel-electric locomotives that are now in service. SBB has converted ten electric shunters and will order four BB electric road locomotives in 1978 if the conversions prove successful. Dr. Weber invited the IPEEP team to return for continued information exchanges as needed.

With respect to the list of questions and data categories for foreign suppliers, Dr. Weber stated that IPEEP should work directly with SIG (or other appropriate supplier) on new equipment and data, and deal with SBB on test programs. Inasmuch as SIG has supplied the necessary Phase I data previously, there was no need to review questions A.1 through A.10. The list of data requirements covered under D.1 through D.8 will not be required until Phase II for the SIG built cars. IPEEP was invited to observe both the commercial and winter tests.

Upon conclusion of the meeting with Dr. Weber of the Swiss Federal Railways, the group traveled to Zurich for additional discussions with SIG. Messrs. Bernhard Huber (Chief, Preliminary and Production Engineering) and Paul Reithaar reviewed the status of the Type III car program. The trip from Bern to Zurich was made aboard the Swiss Express, a train with a coach consist of Type III SIG cars. The cars now in service have had the body-tilting mechanish and sensors deactivated; the suspension system is locked with respect to the active elements of carbody tilting. When the component evaluation program of SBB has been satisfactorily completed and all test requirements met, the system will be made operational.

Ride quality aboard the Type III coach was good. Natural body frequency vibrations were noticeable at mid-car. The most comfortable ride was obtained at the car ends immediately above the trucks.

4.2 May 19, Thursday

This was Ascension Day, a national holiday in most of the countries in Europe. Business offices and plants were closed Thursday and Friday in France, Italy, and Switzerland. The IPEEP group used the time to travel by train from Zurich to Paris for the concluding discussions with SNCF. The trip was made aboard TEE L'Arbalete. Once again, the ride quality, quietness, and excellent schedule time of TEE trains was appreciated. The train was hauled by a SBB re 4/4 electric locomotive to Basel, and thence by a SNCF diesel-electric to Paris.

4.3 May 20, Friday (SNCF)

The concluding session with SNCF began at 0900 at the offices of the Direction du Materiel. Information concerning the TGV-PSE, which had been requested previously, was reviewed in detail at this meeting. The people who represented SNCF and its principal TGV supplier, Alsthom-Atlantique, were as follows:

Direction du Materiel:

Mr. Andre Portefaix, Deputy Director
Mr. Raymond Garde, Chief Engineer, Rolling Stock Design
Mr. Jean-Marie Metzler, Principal Engineer
Mr. Guy Senac, Principal Engineer
Mr. Alain Moreau, Senior Engineer
Mr. Serge Montagne, Deputy Principal Engineer, Dept. of Track Research and Studies

Alsthom-Atlantique:

Mr. Michel Gaudichon, Director, Traction Group
Mr. Thomas H. Floyd, Jr., DGA International, representing Alsthom in the United States.

A brief discussion of SNCF experience with high-speed operations preceded their response to questions (appendix A) submitted earlier. With respect to train evaluations, SNCF cautioned that the train is only one part of a system; other parts are the track and catenary. The interactions of all must be considered.

If high-speed operations will not involve speeds above 200 kph (124 mph), good results may be obtained with improvements to track and rolling stock only. There is no need to rework the subgrade. However, if operations are to be in the speed range from 250 to 300 kph (155 to 186 mph), it is necessary to rework the subgrade as well as to improve track, catenary, and rolling stock.

SNCF stated that if the TGV.001 were to come to the United States it would have to operate on track that is of comparable quality to that in use in France. The TGV-PSE, incidently, would not be available before 1980. Mr. Mitchell observed that the United States won't have good track before 1980-1981 so IPEEP tests would have to be conducted in France (for the TGV). It was also noted that the TGV.001 test program ends in December of 1977.

It was agreed that we must work out a concurrent test and information program for the period prior to 1980. IPEEP wishes to have the information requested in the list (appendix A) provided earlier; this is for preliminary evaluation in phase I. We will negotiate for additional data and testing for those trains that make phase II. Such negotiations would be between UII and SNCF or Alsthom; only a memorandum of understanding is possible between FRA and SNCF.

Mr. Mitchell outlined the following program:

a. The initial step is for IPEEP to obtain currently available data for train performance calculator (TPC) runs.

If there is continued IPEEP interest,

b. Agreements (MOU) between FRA and SNCF, and/or a contract between UII and French supply industry. These will:

(1) Describe terms and conditions, and

(2) establish a potential lease agreement.

If there is continued IPEEP interest,

c. Tests will be conducted on SNCF track to:

(1) Obtain necessary technical data that has not been gathered already, and

(2) verify ride quality with United States test equipment.

d. Ship the train to the United States for test and demonstration, or

e. Amtrak may make a lease/purchase option agreement.

It was then agreed that the information needed for phase I of IPEEP (e.g., questions A.1 through A.10) would be provided soon and free. This information will come from the suppliers. Liaison between SNCF and IPEEP will be provided by Mr. Blumstein of SNCF's New York office; liaison between Alsthom-Atlantique and IPEEP will be provided by Mr. Floyd of DGA International in Washington.

SNCF and Alsthom will provide information on the electric version of the TGV-PSE as it will be built for SNCF; it will not be an Americanized version designed to meet United States specifications. The IPEEP team agreed to accept data on that basis; it was noted that all foreign equipment considered in IPEEP will be evaluated on an as-built basis, and that United States trains are handicapped by weight in the train performance computer runs. SNCF then stated that its suppliers could build any type of train: turbine, diesel, or electric.

A point-by-point discussion of the questions previously submitted to SNCF (appendix A) then followed. The SNCF and Alsthom responses are contained in appendix D.

5.0 Meeting Highlights - England

5.1 May 23, Monday (BR)

The initial meeting with British rail officials was held at the British Rail Board headquarters at Marylebone in London. The following participated on behalf of British Rail:

Lord Garnock
Mr. I.M. Campbell, Member, BR Board
Mr. I.D. Gardiner, Managing Director, BR Engineering Ltd.
Mr. K.V. Smith, Managing Director, Transmark
Mr. J.F. Thring, Commercial Director, BREL
Mr. L.E. Middleton, Director & General Manager, BRE-Metro Ltd.
Dr. K.H. Spring, Head of Research
Mr. K. Taylor, Chief Mechanical & Electrical Engineer
Mr. B.G. Sephton, Rolling Stock Engineer
Mr. D.R. Meek, Director, Transmark

Introductions were made and the roles and missions of each delegation's organization were presented. Mr. Mitchell described the background events that led to IPEEP. Mr. Surkamp described the phases and tasks of IPEEP. Mr. Gardiner then followed with a summary of the HST and APT development programs. Both trains were developed to meet specific commercial objectives, which are, in order of importance: safety, reliability, door-to-door time, and passenger amenities.

It should be noted that BR is not offering high speed per se. Safety objectives are absolute. Reliability is next in importance; the trains must be available for normal operations in all weather. Passenger journey time involves speed if time is to be minimized; time reductions result from improvements in track, signaling, tractive power, and rolling stock. Passenger amenities must be equal to the competitor's (automobile, bus, or airplane); noise levels must be low both inside and out, and other human environmental factors must be considered.

New equipment is needed for "renewal time" in the 1980s. The last major motive power conversion undertaken by BR was that of replacing steam locomotives with diesel-electrics in the 1950s and 1960s. BR considers 20 years as a useful life for traction equipment.

Several alternatives were open to BR. One was to develop a train based on existing technology; the other was to perform the R&D for an advanced technology train. The solution was a so-called "British compromise" to go for both.

The High-Speed Train (HST), also known as the Intercity 125, was developed for renewal of diesel service. The HST generally operates with two locomotives and seven cars. The locomotives are used in a push-pull arrangement with one at each end of the train to reduce static rail loads. The train has worked very well mechanically and electrically.

There are 27 HSTs in the Western Region and 32 more will operate on the East Coast line. There will, in all probability, be an additional 45 to 50 HST trainsets built. The train has made a significant service contribution by increasing the number of passenger journeys by 20 percent.

The Advanced Passenger Train (APT) was developed to resolve high-speed curving problems. The experimental version (APTE) was turbine powered. BR is now building three preproduction versions (APTP) that will be electrically powered. A typical consist will be a rake of six trailer cars, two power cars, and another rake of six trailer cars. One power car is complete and the second is nearly finished; four trailer cars were due for completion in June or July.

In response to a question regarding the BR decision to build an electric version of the APT rather than the turbine version, it was stated that (train for train) the total life cycle cost is two to one against the turbine relative to electric power. The APTP program will ultimately require 50 to 60 trainsets. BR will build 20 trainsets a year after 1981. The prototypes will enter revenue service in October 1978, and production versions will begin to supply full service in May 1979. The train is designed for 150 mph running speed, but will be put into service at 125 mph. It was also learned that BREL may also develop a diesel version of the APT if the electrification program is not continued to the East Coast lines. Furthermore, if someone were to invent a good heat exchanger they would take another look at a gas turbine powered version of the train.

An HST inspection tour was provided in the afternoon. It involved a trip from London's Paddington Station to Bristol and return aboard the HST. The line is being improved and curves are being straightened; a number of work crews were observed. Opportunities to ride in the locomotive cab were available; it proved to be quiet, air-conditioned, and the locomotive possessed very good ride quality. While at Bristol, the group inspected the shops which handle light running repairs, and provide service and inspection facilities for the HST. Each HST travels about 1,000 miles a day for 300 days of the year. Participating in the HST tour on behalf of BR were:

Lord Garnock
Mr. I.M. Campbell
Mr. D.R. Meek
Mr. E.S. Burdon, HST Engineering Design Manager
Mr. J. Bourne, Service Group Manager, Western Region

5.2 May 24, Tuesday (BREL)

Departed London at 0750 for British Rail Engineering, Ltd. facilities of Derby. Received briefings and saw film "Intercity-125." The following British Rail people participated in the Derby program:

Mr. John Thring
Mr. Sidney Burdon
Mr. Rupert A. Powell, Manager Commercial Services, BREL
Mr. Alan Wickens, Director of Research Laboratories
Mr. Peter Grey, Works Manager, Derby Litchurch Lane

Mr. Burdon, HST Engineering Program Manager (or equivalent), briefed the IPEEP group on the engineering aspects of the trainset. Locomotives and cars are built on the same basic chassis or frame to provide a modular construction technique. The power car (locomotive) is shorter than the Mark III coaches; hence it has excellent curve capabilities.

Each power car weighs 69 tonnes (76 tons), is 93 inches in overall width, and has a 2,250 hp diesel engine installed which drives a 1,468 kW (1,970 hp) traction alternator. Multiple unit operation is provided by means of a 32 wire train-line.

Power car cab ends are made of plastic that is 50 mm thick (about 2 inches). Laminated windshield has high impact strength; it can withstand impact of a 2-pound cube striking corner-on at 180 mph. The train is designed to meet the UIC buff load strength of 200 metric tons (220 tons avdp).

BREL conducted an impressive analytical program in the development of the HST. An initial analysis was made of running stability using an analog computer. The design was refined with a digital model; this established the lateral, longitudinal, vertical, and torsional stiffness of the car bodies. Stiffness properties were selected for a design speed of 140 mph.

The initial running trials indicated truck stability problems with the powered bogies. Changing the stiffness of the rubber elements of the primary suspension corrected the problem.

All UIC (Union International des Chemins de Fer) ride quality criteria have been exceeded. The power cars have a ride index of 3.75; passenger cars have an index of 2.75. The UIC TEE standard is the range of 2.5 to 2.75.

Excellent fatigue test laboratories are available at Derby. Any rail car component may be tested including full-scale trucks. Techniques have been refined to the point that fatigue life predictions are made on bogies. The HST's BT-10 truck is guaranteed for 15 years of crack-free service. Static load tests are made; these are followed with running tests to record strain gage readings (technique applies to a given design, not each production unit).

Weld design details are stored in computer. If weld damage occurs, it is associated with mileage record at the point of damage. In this way, mileage limits are then set. (Average annual mileage for an HST in the Western Region is 3,000,000 miles.)

BREL strongly advocates welded truck frames since sectional properties can be determined precisely; cast frames are susceptible to flaws. Penetration welds are made on all truck frames. If the initial weld passes 100 percent X-ray inspection the second beads are laid in. (Comment: Visual inspection of BREL welds indicated that workmanship was of highest level in industry, if not surpassing others.)

Design criteria for the HST bogie required that the P_1P_2 loads not exceed those of heavy diesel locomotives at 100 mph. (P_1P_2 loads are vertical loads encountered in running over rail joints.)

Truck load was given as 45 metric tons (99,207 pounds). Truck weight is 12.5 metric tons (27,558 pounds) and frame weight is 1.5 metric tons (3,307 pounds). The unsprung mass is 2.2 metric tons (4,850 pounds) per wheelset. The suspension is soft with large amounts of travel allowed; motion is controlled by dampers.

British Rail practice is to start with a hollow or worn wheel profile and allow 4 mm for wear (8 mm on diameter). The suspension is designed to accommodate the worn contour. Apart from flats, the profiles are re-turned at 180,000 miles. BREL feels it necessary to place very tough specifications on the rubber used in the Alsthom links and damper ends.

BREL does all of the design work for locomotives (power cars) and coaches. Component (e.g., motors, springs) performance is specified and purchased from vendors. The HST production rate is 30 trainsets a year although plant capacity is twice that.

HST fuel consumption (based on a sample of 21 trainsets over a 3-week period), for a variety of conditions (i.e., running, idling) is 3.62 liters per kilometer per trainset (2 + 7 consist). This is the equivalent of 1.58 Imperial gallons per mile.

Grade performance was stated as from 1:40 to 1:50, and 1:37.7 for wet rail and warm motors. The HST has climbed a long hill with one power car shut down. Although the speed dropped to 15 mph, the traction motors did not overheat. The train has also achieved 110 mph with one locomotive inoperative.

5.3 May 25, Wednesday (BREL)

The second day at Derby was focused on the APT program. Participating on behalf of BREL were:

Dr. David Boocock, APT Design Engineer
Mr. Roy Pouley, APT Engineering
Mr. Mike Newman, APT Engineering
Mr. Roger Kent, APT Engineering
Mr. John Thring
Mr. Rupert Powell

Dr. Boocock summarized the background developments that led to the Advanced Passenger Train (APT). One of the first problems to be solved was that of BB type truck (bogie) hunting. A complete study of hunting turned into an even more complete study of dynamics by Alan Wickens. Higher speeds then seemed possible when hunting problems were solved, and an extensive technical analysis followed.

An experimental program, begun in 1967, led to the development of the APT-E (experimental) in 1973. The APT-P (prototype) engineering program began in 1973. The design is 99 percent complete. Equipment proving trials for the first power cars and coaches are to be held in Scotland in February of 1978, and the first production train will be available for trial running as a trainset in late 1981. Service is expected to begin in 1982. The ATP-P will operate with a 25 kV, 50 Hz traction supply on the West Coast line at speeds as high as 250 kph (155 mph).

The APT-P was not designed to be a prestige train or one that offers premium service on the line. It will be used to meet the demands of general revenue service so that older equipment may be retired. The APT must live with the existing system of tracks and signals. The train has been designed with energy conservation in mind.

For service on non-electrified lines, BREL recommends diesel rather than turbine power. They are now in the preliminary, or feasibility determination phase of a diesel version of the APT. Power cars will be rated at 3,000 horsepower each.

Major factors which influenced the APT-P configuration were:

Journey times,
comfort,
energy efficiency,
low noise,
maintainability,

no infrastructure costs, and
same cost per seat mile as HST.

A 15 to 30 percent increase in ridership is expected with the introduction of APT service. The train should provide a 20 to 40 percent decrease in travel times depending on curves. British Rail now operates 4 degrees (approximately 4 inches) of unbalance on curves; the APT-P will be able to operate at 9 degrees (about 9 inches) cant deficiency (unbalance).

The tilt system is power actuated, rather than pendulous, using electrohydraulic components. Maximum roll rate is 5 degrees per second. Tilt is achieved by moving the bolster (swing arms are used to control the location of the roll center). The system uses two sensors per car which is the equivalent of one per axle for the articulated coaches. (BREL has tried to reduce the system analysis to 35 degrees of freedom.) Air bags that are mounted on the bolster roll with it.

BREL has conducted a failure analysis of its tilt system. This resulted in an actuator system designed for maintainability; the maintenance concept is one of modular replacement that allows equipment substitution so that faulty equipment can be sent to a diagnostic shop.

On the subject of track forces, BREL has increased the centrifigul forces while reducing dynamic forces produced by the APT. They have aimed at reducing the unsprung mass to 1.5 metric tons (3,300 pounds) per axle. A prime objective is to keep weight off the bogies and to keep truck frame weight down. The transmission is frame mounted and the motors are body mounted (inside the power car). Vertical dynamic loads were limited to those of present day stock.

The use of a lateral-to-vertical load ratio was emphasized, and BREL uses SNCF criteria as a guide. They measure the forces at the bogie and calculate wheel forces from there. This technique is based on a comprehensive calibration in which wheels, rails, and roadbed forces were measured.

APT car rollover occurs at about 26 degrees (nearly 28 inches) of unbalance, and lateral track shift occurs at 17 degrees of unbalance. Track shift was determined by use of simulated loads at an actual line site. There has been no evidence of tendencies to derail by flange-climbing.

BREL has made TPC analysis of the Northeast Corridor with service provided by the APT-P. Between Washington and Baltimore it is possible to save time and kilowatts by straightening curves in two places. Copies of the TPC runs were given us; data was plotted by milepost.

The same type of analysis was made for APT-P runs between New York and New Haven. Without track improvements, the APT-P provides an 89 mph average compared to 47 mph for conventional equipment. (BREL did not consider slow orders in effect.) Running times were 51 and 64 minutes, respectively. The results of other TPC runs were presented; these compared the Shinkansen cars, Metroliner, HST, and APT-P.

It was estimated that it would take 3 years to redesign and build a new APT for use in the United States. This assumes no delays. BREL could participate as an active partner under a license basis.

Wednesday afternoon was used to inspect the locomotive works at Derby Litchurch Lane. New Mark III (HST) coaches and the APT prototype trailer cars are built at Litchurch Lane. They also inspect and overhaul diesel-electric locomotives, build bogies (powered and trailer), and rebuild motors and gear boxes. Six power cars are being built for three APTs, and prototype bogies (powered and trailer) for the APT-P are also under construction there.

The first APT-P power car has been completed, and the group took the opportunity to inspect it. The car had just been mounted on its trucks and the electrical and traction equipment had been installed. When asked if much electro-magnetic interference was expected, the response was that a slight amount would result from pantograph arcing. This would be in the VHF range caused by 25 kV; most TV is UHF (in England); hence it will not be noticed.

5.4 May 26, Thursday (BREL)

The Crewe Works were inspected after an automobile trip from Derby. The works specialize in the manufacture and overhaul of diesel-electric locomotives. The HST power cars are built in Crewe. Time required to build one HST locomotive is 800 hours (two 40-hour shifts per week).

5.5 May 27, Friday (BRB)

The concluding session with British Rail officials was held at Marylebone in London. Representing British Rail were:

Lord Garnock
Mr. R.L.E. Lawrence, Chairman, BR Board
Mr. I.M. Campbell
Mr. I.D. Gardiner
Mr. K.H. Spring
Mr. L.E. Middleton
Mr. B.G. Sephton
Mr. J.F. Thring
Mr. D.R. Meek

Mr. Mitchell reviewed our experiences of the week and congratulated the British Railway Board (BRB) on the excellent arrangements for conferences and inspections. There were several questions related to the relationship of IPEEP to Amtrak; these were answered by Mr. Mitchell. Interest in a diesel version was expressed. Mr. Campbell stated that this version is "well on towards determining the feasibility but still well downstream." The reason for the diesel is the lack of capital for main line electrification, particularly for the East Coast Line. BRB is also considering the need for new traction motors to go aboard a diesel electric version.

The future program for the APT involves 50 or 60 trains. These will be built at the rate of 20 per year starting in 1981. BRB plans to initiate service with the prototypes in a year with full service at 155 mph beginning in May of 1979. Main line electrification is believed economically sound, and independent of primary energy sources.

The list of questions to potential suppliers (appendix A) was reviewed by Mr. Surkamp. British Rail responses on each item are provided in appendix E. Supsequent liaison between BREL and UII should be made through Mr. John Thring.

APPENDIX A

Improved Passenger Equipment Evaluation Program

Questions For Potential Suppliers

A. Performance and Physical Data

Can you provide:

1. Schematics and structural drawings of the trains to be evaluated?

2. Static and dynamic clearance outlines?

3. Location of center of gravity, maximum lateral offset of center of gravity, and maximum roll angle? (This data required for both the inactive and active conditions of active suspension cars and trainsets.)

4. Continuous and short-time (5 minute or 2 minute) rating of the weakest element in the propulsion system?

5. Tractive effort vs. speed curves for the following ratings: maximum, one hour, and continuous?

6. Braking effort vs. speed and rate curves for each mode of braking employed by the test vehicle?

7. Weights of each vehicle involved in the train, as well as the axle loading?

8. Train resistance data for the subject vehicles through their entire speed range?

9. Train strength including compressive loads at centerline draft and 12 inches above centerline draft, buff load, collision post shear strength at bottom (or equivalent), and anticlimbing resistance capacity and means?

10. For propulsion systems under consideration, what is their thermal time constant? We generally define thermal time constant as the time in minutes required to bring any critical component of a propulsion system to a temperature that should not be exceeded when the propulsion system is continuously subjected to its maximum propulsive and braking tractive efforts. Temperature measurement should be made after equipment is thoroughly warmed up, e.g., after a revenue run. (Note: Regular Metroliners have a thermal time constant of 15 minutes; the Upgraded Metroliners have a thermal time constant of 30 minutes.) Experimentally, maximum tractive effort is applied by going alternately from power to brake, and a dynamic brake equal to propulsive effort is implied.

B. Test Operations

1. Is there any objection to the measurement of on-board and wayside performance and force data by the IPEEP test team? We plan to provide the

necessary test equipment.

2. What can be measured? Are there restrictions on the measurement of any test parameters?

3. It is our intention to take the data obtained in our tests to the United States for reduction and analysis. Will you accept the results of our tests on this basis?

4. Is any of the data, which will be acquired on the tests or from preliminary tests, proprietary or is it public?

5. Assuming that test data is taken by you (supplier or railroad), how will it be made available to the evaluation team?

6. What, if any, restrictions will there be for the technical personnel on riding the equipment cabs and cars in test configurations, both in this country and abroad?

7. How will track geometry be defined (to assure comparability of test data from one site and one train to others)?

8. Will translators or interpreters be available to the evaluation team?

9. Will there be any differentiation between FRA employees and consultants with regard to test data and the conduct of the tests?

C. Contractural Aspects

1. Will you accept a U.S. Government Bill of Lading as a complete transportation contract for the purpose of bringing your train to the United States? If not, what arrangement(s) would you contemplate?

2. How would you propose to let us use your train (e.g., by lease)?

3. If leased, from whom will the equipment be leased?

4. How would you support the equipment while it is in transit and in the United States? How many of your personnel would you want to send? What would be the cost?

5. Who will carry insurance for the equipment and our personnel abroad and in this country?

D. Data Categories

Questions under A, B, and C relate to information needed to begin the preliminary train evaluation. Additional information will be required for subsequent detailed evaluations, and the attached list of data categories identifies the data requirements of IPEEP.

Can you provide the data described in the attached list, and do so within 60 days?

- 1.0 Drawing Type Information Required
  - 1.1 Clearance diagram
  - 1.2 Equipment location schematic
  - 1.3 Train configurations (vehicle makeups)
    - 1.3.1 Train length
    - 1.3.2 Maximum number of passengers
  - 1.4 Description and types of cars
- 2.0 Basic Vehicle Dimensions
  - 2.1 Length over couplers
  - 2.2 Length over buffers
  - 2.3 Pantograph lockdown height (electric)
  - 2.4 Maximum pantograph running height (electric)
  - 2.5 Carbody height
  - 2.6 Distance between bogie centers
  - 2.7 Carbody width (maximum at/height)
  - 2.8 Height of carbody above rail (maximum)
  - 2.9 Average carbody width
  - 2.10 Frontal area (lead cars only)
  - 2.11 Average carbody length
  - 2.12 Truck wheel base
  - 2.13 Axle centers
  - 2.14 Minimum curvature radius
  - 2.15 Center of gravity height
  - 2.16 Maximum lateral offset of center of gravity
  - 2.17 Coupler height
  - 2.18 Platform height required
- 3.0 Static and Dynamic Weights
  - 3.1 Weight in working order
  - 3.2 Maximum weight with full passenger load
  - 3.3 Weight per axle
  - 3.4 Weight on driving axles
  - 3.5 Unsprung weight
- 4.0 Strengths
  - 4.1 Compressive loads
    - 4.1.1 At centerline draft
    - 4.1.2 Twelve inches above centerline draft
  - 4.2 Buff load
  - 4.3 Collision post shear strength at bottom connection
  - 4.4 Anticlimber capacity
  - 4.5 Structural arrangement (to check design against applicable rules and standards)
  - 4.6 Truck to carbody attachment
    - 4.6.1 Vertical
    - 4.6.2 Shear
  - 4.7 Jacking provisions
- 5.0 Performance Characteristics
  - 5.1 Maximum service speed
  - 5.2 Maximum tractive effort
  - 5.3 Continuous tractive effort (lbs. at MPH)
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DATA CATEGORIES - IPEEP

Trip Report
Federal Railroad Administration
&
Unified Industries Incorporated
IPEEP Train Review Survey in England, France, Germany, Italy, Sweden, and Switzerland

September 12 to 23, 1977

Prepared for

DEPARTMENT OF TRANSPORTATION

FEDERAL RAILROAD ADMINISTRATION

Office of Research and Development

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TRIP REPORT

Visit to England, France, Germany, Italy, Sweden, and Switzerland
September 12 to 23, 1977

1.0 Introduction

An overseas data gathering trip was made in September under the Improved Passenger Equipment Evaluation Program (IPEEP). Six countries were visited in order to obtain detailed information on specific items of train equipment. This third IPEEP trip was essential to the timely completion of preliminary equipment evaluations inasmuch as some critically needed information had not been provided previously.

1.1 Delegation

The IPEEP technical team was composed of six members as follows:

Name	Affiliation	Specialty
Mr. Alexander F. Lampros	FRA, Office of Passenger Systems	IPEEP Project Engineer
Mr. John A. Bachman	Unified Industries Incorporated	Technical Program Manager
Dr. Richard A. Uher	Carnegie-Mellon University	Systems Analysis, Train Performance
Mr. Robert B. Watson	L. T. Klauder & Associates	Operational Characteristics, Mechanical Equipment, Passenger Amenities
Mr. Howard C. Meacham, Jr.	Battelle Columbus Laboratories	Suspension Characteristics, Ride Quality Dynamics and Safety
Mr. John W. Marchetti	J. W. Marchetti, Inc.	Electrical Engineering

1.2 Itinerary

Dates	Country	Topic
September 12	England	APT at British Rail
September 14, 15	Germany	ET 403 at DB
September 16	Sweden	X2, X15 at ASEA
September 19	France	TGV at Alsthom
September 21	Switzerland	Type III Tilt Cars at SIG
September 22, 23	Italy	Y0160 at Fiat

2.0 English Equipment

This section addresses the High Speed Train (HST) and the Advanced Passenger Train (APT).

2.1 Disscussion and Meeting Highlights

September 12 - British Rail Technical Center, Derby, England. The principal contact at the Technical Center was Roger Kemp, APT Electrical Design Engeneer. Other BR persons contacted were:

Mr. Sid Burdon, HST Engineer
Mr. Larry Shaw, Design Engineer, Locomotives
Mr. Allan Beacon, Mechanical Design Engineer
Mr. Dave Rollins, APT Project Engineer for BREL
Mr. Denis Lees, Manager, Locomotive Works
Mr. Harry Christian, HST Bogie Mechanical Superintendent

Initial discussions centered on electrical traction and braking of the APT. Mr. Kemp explained that the electrical control equipment was manufactured by ASEA and was based on the equipment in the Rc3 and Rc4 Locomotives.

Previous visits resulted in fairly comprehensive HST data gathering success. Messrs. Burdon and Christian were consulted with respect to a few missing details.

As a miscellaneous item, it was noted that British Rail schedules slack time in operation at a rate of 4 minutes per hundred miles.

In the afternoon, the team toured the Litchurch Lane carriage works and the locomotive works. Three APT train sets are now being built, each consisting of 2 power cars and 12 coaches. An APT power car was inspected in the electrical test bay. HST trucks were also inspected in the overhaul facility in the locomotive works.

2.2 General Status and System Description

The HST is in operation on a regular basis carrying the designation "Intercity 125." The previous IPEEP visit to British Rail Engineering Limited (BREL) resulted in the acquisition of 95 percent of the information needed to evaluate HST equipment.

The APT configuration is still evolving although most of the equipment design decisions have been made. The APT consists of two power cars located in the center of the train propelling eight unpowered cars on each end of the train.

The first power car has completed mechanical tests by being towed by HST equipment. Electrical tests are underway on the second power car; these are being conducted in stages. The coaches will be similarly tested next year. Upon completion of the tests, the train will be tested as a unit. The first commercial runs are to be made with three trains on the London-Glasgow route in 1979.

The APT was designed originally as a 14- or 15-car train, but emphasis now is on an 8-car train. Instead of two groups of eight articulated cars, one group or rake at each end of the two power cars, the eight-car consist may have one power car located at the end of the train. An engineman's cab would be fitted to the power car.

Cab signaling and speed control will be used by BR and will be applicable only to high-speed equipment, while allowing other trains to operate in their conventional manner. The West Coast electrified line for which the APT was designed has a large number of curves. In order to achieve a higher schedule speed, a tilt body was deemed necessary for passenger comfort. Because of the higher schedule speed requirement on present track within present signaling constraints, higher braking rates were also required. This led to the development of a hydrokinetic brake.

Articulation was selected to provide a generally lightweight train. This concept allows higher acceleration and braking rates because of the weight reduction. Light weight is also emphasized in the aluminum construction of the passenger coaches. The present consist is actually locomotive-hauled with the locomotive(s) in the center of the train.

2.3 Track

BREL promised to provide copies of BR track standards. British track is probably quite comparable to that in the United States, though better maintained. According to British Rail, roughly 50 percent of the routes are made up of curves, and of these, about 50 percent are relatively sharp. Main line curves are normally a minimum of 30 chains radius (2.5° or 1,980 ft) but generally curve radii are on the order of 60 to 70 chains (1.3 to 1.1° or 3,960 to 4,920 ft). The 30-chain figure is a minimum, with accompanying speed limits of 60 to 70 mi/h. Due to their maintenance procedures, track geometry is probably better than the average in the United States.

Average speed of their conventional trains on curves tends to be determined largely by speed restrictions due to the passenger discomfort limit rather than any safety limit. With the APT, the plan is to increase cant deficiency to 9° (9 in), which will raise the maximum speed through the curves by 20 to 40 percent. On the restrictively curvy London to Leicester route, the APTE, operating with a maximum speed of 200 km/h (124 mi/h), made the 159-kilometer (98-mile) trip in 58.5 minutes, or an average speed of 163 km/h (101 mi/h). This gave a time of 1 hour and 2 minutes compared with the present day timing of 1 hour and 24 minutes.

2.4 Equipment Details

General - The HST reflects current state-of-the-art diesel-electric motive power and disc braking systems. The design speed is 125 mi/h. Fuel consumption was quoted at 0.365 lb/hph; the idle value was not available, but BREL promised to send it.

The APTP represents significant advances in rail technology with respect to motive power concepts and brake equipment. The design speed is 150 mi/h (250 km/h). The experimental version (APTE), powered by gas turbine driven alternators, proved to be unfeasible with respect to fuel (energy) consumption.

For the electric prototype version (APTP), BR selected an ASEA propulsion system rather than develop their own.

Significant features include the use of mineral insulated buss bars for heavy conductors in the cars, and the application of basic ASEA Rc locomotive propulsion technology. ASEA provided the total electrical propulsion system. A motor alternator set is used for auxiliary power. The hydrokinetic brake, which is used on all axles of the trailer cars as well as in the drive train of the power cars, is an interesting and innovative design that deserves further study.

The ASEA system of thyristor control is well proven. BR was able to get the horsepower needed to achieve design speed requirements and could concentrate on refining the remaining mechanical system problems. These include car and truck design, tilt design, braking system, safety systems, and other mechanical aspects. The current APT power car (cabless locomotive) has body mounted traction motors which drive a gear box on each axle by means of a Cardan shaft. The body mounted hydrokinetic brake is coupled through the same shaft.

Each motor is fed from two controlled rectifiers in series. Smoothing of the current is accomplished by reactors in series with the motors with one reactor per motor. (Circuit diagram schematics were provided to explain the arrangement.) The controlled rectifiers are oil cooled; this method of cooling is a new technology item. The reactors are also oil cooled. Capacitors are used for power factor correction. It is not certain how much correction is provided.

The LJMA401F traction motors are scaled down versions of motors for the Rc3 locomotive. The motor rating is 740 kW at the maximum rotational speed of 2,600 r/min. They have separately excited fields. The controlled rectifiers, of which there are four, are separately removable and can be handled by two men.

BREL suggested that details of the propulsion system such as Torque/Speed/Amp curves, reactor, transformer, and motor impedances be obtained from ASEA. In BR train performance runs, an average mechanical-at-rail to electrical-at-wire power conversion efficiency of 81 percent was used. No information was available on minimum field strength.

The APT pantograph is a two-stage unit. The first stage is a standard Faively with high-speed performance capabilities that a single main frame type does not have. The second stage provides a low-inertia high-frequency response to catenary or track irregularities. The pantograph is mounted to the body to compensate for car pitching motions, and to the suspension to compensate for roll and to bypass the tilting motion of the body. The compound pantograph has been tested at speeds to 130 mi/h with a standard locomotive.

Vacuum interrupters are presently being used for primary fault protection and isolation; however, difficulty has been experienced with the first power car now under test. BREL will resort to the air blast breaker. The BR power supply was described as "not stiff." The APT will operate on 50 Hz, 25 kV, however the British cope with regulation of the 25 kV catenary supply over the limits 28 kV to 16.5 kV; this indicates a very soft system.

Mineral-insulated copper-sheathed cables are used in wiring the car bodies of the APT. These cables use a magnesium carbonate powder as insulation. The powder is held in position by a tight fitting copper sheath which is extruded around it.

The speed control system employs a transmitter in the train which energizes a transponder located in the track. The transponder then sends speed information to a receiver in the locomotive which gives speed limit information to the display in the cab.

Train resistance is estimated using a special formula developed by British Rail. The polynomial equation used by BREL is not the same as the Davis formula.

In designing the APT to meet stopping requirements, BREL found that the relatively low number of powered wheelsets required an additional mode of braking for the speeds involved. Electric dynamic braking on the power cars alone was insufficient, and disc brakes of sufficient size would be unnecessarily heavy and bulky. Consequently, it was decided to adopt an additional mode in the form of a hydrokinetic brake. Such a system when combined with tread brakes, provides a blended system that is comparable to electric dynamic plus tread braking. The hydrokinetic brake develops a torque when filled with fluid and is mounted inside a hollow axle on all except driven axles. The system does not fade, and it was thoroughly tested from 1972 to 1976 on the original turbine-powered experimental train. It is effective at high speed and degrades in effectiveness as the speed is reduced. At zero speed it must be backed up by a friction brake. BREL provided a detailed comprehensive description of the hydrokinetic brake system.

Basic design philosophy is to keep the truck simple and the wheelset, which is a removable item, complicated. The outboard journal contains the water and oil seals for the braking system. The main reservoir line is the only train line for air. Whether the complexities introduced mechanically by rotating water joints and control schemes more than offset the purely thermal advantages of this brake is something that can be determined only by experimental trial. In this hydrodynamic joule heating brake, the British are taking a bold step to secure a real advantage to the braking of a high-speed train. It is independent of catenary power and is on a per axle basis. Approximately 30 gallons of water are used for each axle.

There are two motor-alternator (MA) sets in the cars adjacent to the APTP power car, each of which is rated at 430 kVA. These must operate with an overhead supply voltage which varies between 16.5 and 28 kV on a nominal line voltage of 25 kV.

There is one dead section approximately every 30 miles of running, and the inertia of the MA would normally keep the auxiliaries operating through this section. A diesel engine is mounted in the front and rear cars in the event of loss of hotel power.

HST General Truck Design - Design of the HST trucks is modern but not radical. A welded steel rigid H-frame is used, with primary suspension by radius arms, coil springs, and hydraulic shock absorbers. Secondary suspension is by means of four Flexicoil springs per truck, with hydraulic telescoping dampers for lateral and rotational motions of the truck relative to the car body. Disc brakes bearing on the cheeks of the wheels are used, together with a cast iron tread conditioning brake which acts on each wheel during service application. There are two trucks per power car and trailer car -- no articulation is used. Traction and braking forces are transmitted between the truck and the car body by precompressed rubber elements and a pivot casting.

Static axle loads are 17.5 metric tons (about 38,600 pounds) for the power car and between 8 and 10 metric tons (17,600 and 22,000 pounds) for the trailer car. The power car axle loads are the highest of any of the six trains evaluated, as would be expected, since the power car is essentially a locomotive. The unsprung mass is 2.2 metric tons, or 4,850 pounds per axle, making this the highest of any of the trains evaluated.

The truck has been extensively tested in service. The fact that the HST is in commercial service on track which is probably comparable to United States track, would indicate that there are no undue development problems to be solved, at least for the type (speed) of service it is in. The HST underwent a comprehensive testing program, during which a world diesel speed record of 230 kilometers per hour was attained.

Some ride quality difficulty had been encountered with the HST truck on curve worn rail conditions, wherein rail which has been worn out on one side is turned and applied to the other side of the curve. This caused some trouble with the worn wheel profile, but it has been in use on the HST up to this time.

The power car truck has undergone development changes. For example, several different spring rates and elements in the primary suspension were tried, and the design which was found to give the specified spring rates with the greatest simplicity incorporated Clouth rubber rolling ring spring units. This suspension was undergoing extensive tests in 1975 and was to be adopted if the tests were successful.

APT General Truck Design - The APT truck design is perhaps the most radical truck encountered on the trip; however, it is based on extensive research and testing by the English over the past 10 years, and British Rail pioneered in the theory of designing a truck with worn wheels and specialized primary suspension such that it would not flange on curves.

Primary suspension is by means of four coil springs per axle. On the power cars, the secondary suspension is by means of four large Flexicoil springs rather than air springs. There are three different trucks per trainset:

a. Power car truck.

b. Articulation truck.

c. Front or driving car trucks.

Since the trucks are like no others a couple of features should be mentioned. One is the transmission of power, which is accomplished by a long

Cardan shaft (about 8 to 10 feet in the power car) running from a gear box suspended from the truck frame. A flexible quill drive goes from this gear box to the axle, thereby minimizing unsprung weight on the axle.

The tilting mechanism is said to have the capability of reducing impact loading on the rail by a measurable margin by keeping the cars from going against their lateral stops. Power cars are also tilted, although it is obviously not necessary for passenger comfort. The pantograph has a tilt-compensating mechanism which operates in conjunction with the tilt of the car bodies. APT can operate at 9° tilt with 9 inches of unbalance, although BREL did not state the exact level of unbalance that will be operated. A tilt rate of 5° per second can be obtained. The train has been tested with a tilt mechanism failure simulated to keep the body in adverse or opposite tilt; overturning did not occur until an angle of 24° was reached.

The APT tilt mechanism appears to be simple and straightforward, at least from a mechanical point of view. The bodies of the APT coaches are mounted on air springs which are carried on a U-shaped tilting bolster. The bolster is suspended from a central structural member of the truck frame by two swing-hanger type links. The tilt center is at about seat-cushion level. Hydraulic tilt jacks between the bolster and truck are actuated in response to signals from an accelerometer mounted on the bolster.

Hydraulic fluid for tilt needs special cleaning because of the high pressure (3,000 lbf/in^2) and high velocities at which it works. A special machine which uses a microscope for inspection is required any time a seal is broken.

Because of their light weight, static axle loads on the APT passenger cars are among the lowest, being 13 to 14 metric tons per axle. On the power car, however, the axle load is 17.3 metric tons (38,000 pounds). The unsprung mass is among the lowest of the trains at 1.5 metric tons, or about 3,300 pounds per axle.

HST Body Structure Design - The underframe and stressed skin body sides of the power car are of welded steel construction. Finite element computer programs were used to optimize the structure. The trailer cars are the Mark III coach, which is an evolution of the BR Mark I coach introduced into service in 1951. The stressed skin structure is of integral all-welded mild steel construction; a steel underframe is used.

Special attention has been given to crew protection, with a cab made as a separate demountable unit resiliently mounted on the underframe. It is composed as a "sandwich," having individual inner and outer skins made of glass-reinforced polyester, between which is a polyurethane foam core. This is designed to give a high strength-to-weight ratio and protect the crew from "minor" impacts at high speeds.

APT Body Structure Design - Lightweight steel construction is used for the power car body shells, and welded aluminum construction is used for the trailer cars. In this construction, wide commercial grade aluminum extrusions, running the full length of the vehicle, are seam-welded together using automatic welding techniques. Although the design goal was to have fundamental lateral and vertical bending frequencies of about 15 Hz when fully loaded, information is not available as to whether this goal was reached. It is estimated that frequencies may be lower than that, based on data from other lightweight cars.

Vehicle structures are designed to meet international loading specifications for mainline coaches, including a 200-ton buff load, which meets AAR requirements for trains less than 600,000 pounds. A copy of the specifications -- which the British use and which they provided -- is shown in table 1.

TABLE 1. DESIGN LOAD CASES FOR APT POWER CAR

UIC loads		Application
2,000 kN	(449,600 lb)	Compression at buffing/drawgear positions
400 kN	(89,920 lb)	Compression, 350 mm (13.8 in) above buffing areas
300 kN	(67,400 lb)	Compression at waist line
300 kN	(67,440 lb)	Compression at cant rail
500 kN	(112,400 lb)	Diagonal compression at floor level
1,500 kN	(337,200 lb)	Tension at drawgear (not strictly a UIC requirement)

APT Ride Comfort

a. General Vibration Levels - Vertical and lateral suspensions are designed to have frequencies on the order of 0.7 to 0.8 Hz, which should make a very comfortable ride. Measured body accelerations "on average, good quality, mainline track" are approximately a 0.3 m/s^2, rms vertical, and 0.2 m/s^2, rms lateral, when weighted in accordance with the ISO constant comfort curves.

b. Lateral Accelerations on Curves - The tilt system enables curves to be taken with an unbalance of 9° without affecting passenger comfort. Without tilt body, speed is limited by a value of 0.7 m/s^2 for a net lateral acceleration which corresponds approximately to a 4° unbalance.

c. Interior Noise Levels - Requirements for interior noise are maximums of 68 dB(A) or 76 dB(B), and these values have been obtained in a trailer car section of APTE. The team noted that the floor is suspended by rubber gaskets from the body structure and that insulation material is used abundantly throughout the body structure.

2.5 Technology Items

a. Articulation - Reduced weight by reducing number of trucks per train.

b. Tilt - Higher speeds in curves, thus reducing overall schedule speed.

c. Oil-Cooled Rectifier - Reduction in propulsion system weight. More uniform heat transfer.

d. Separately Excited Motors - Better acceleration at high speed.

e. Mineral Insulated Cables - Reduction of shorts and fire hazard.

f. Hydrokinetic Brake - Requirement for high braking rate with fewer axles.

g. Compound Pantograph - Current collection at high speeds.

h. Body Hung Motors - Reduction in unsprung weight and dynamic wheel-rail impacts.

3.0 German Equipment

3.1 Discussion and Meeting Highlights

September 13 - Travel day

September 14 and 15 - Deutsche Bundesbahn, Frankfurt and Munich, Germany. Dr. Peter Tonn, from the Battelle Laboratory Office in Frankfurt, acted as interpreter in the meeting with DB in Frankfurt on September 14.

Present at the meeting were the following representatives of DB and its contractors:

Mr. Kurt Bauermeister, Ministerialrat, DB Frankfurt
Mr. Axel Guldenpennin, DB Frankfurt
Mr. Hermann Wolters, DB Munich
Mr. Schroder, DB Frankfurt
Mr. Rappengluck, DB Munich
Mr. Dennert, DB Frankfurt (Translator)
Mr. Karl Dreimann, AEG Telefunken
Mr. Fritz, Marten, Siemens AG
Dr. Rudolf Winden, Brown Boveri
Mr. Duba, Linke-Hofrmann-Busch GmbH
Dr. Fahlbusch, MRB
Mr. Kayserling, MAN

A. F. Lampros presented a briefing on the FRA IPEEP program and introduced the Unified Industries team. John Bachman followed with a discussion of the IPEEP tasks, the UII management approach, and the roles of the subcontractors and consultants.

The Germans were very responsive to requests for information for the evaluation of the ET 403 in Phase I of IPEEP. A substantial amount of technical literature was received that covered most aspects of the train. Although most of the material was in English, some will require translation by UII. The IPEEP team will protect proprietary items if these are identified as such to the team.

Mr. Bauermeister pointed out that DB would like to review the results of IPEEP analyses on the ET 403 before it is published. It was agreed that it would be a good thing to review the results of calculations, but that conclusions would not be reviewed with them. This seemed a satisfactory arrangement.

Mr. Dreimann presented a slide briefing on the ET 403, pointing out that the multiple-unit ET 403 was developed as an alternate to locomotive hauled trains for service on existing rail lines. Three prototypes have been built and are being operated in a demonstration program over their intercity network. While the train has demonstrated good performance and reliability, it is expensive to build and maintain as configured. It was subsequently indicated that probably no more will be built.

Mr. Duba followed with a discussion of the mechanical equipment, and Mr. Kayserling gave a technical discussion of the ET 403 trucks. There was ample time given for the UII technical specialists to discuss items in respective areas of responsibility.

The DB arranged for the IPEEP team to ride the ET 403 on a round trip from Munich to Augsburg on September 15. Before boarding the train at 10:20 a.m., there was a period for questions plus an inspection of the train. During the trip the train reached 200 km/h. Acceleration and braking were very smooth. The team was allowed to visit the cab and witness the operation of the automatic train control system. This system is generally similar to the British APT system previously mentioned.

3.2 General Status

The ET 403 was seen by DB as the intercity link required for the post-1975 years; however, the program has not materialized quite as well as had been expected.

Three prototypes have been built. Two are presently being operated in revenue service between Bremen and Hamburg, and one is being used for testing and/or is held on standby should anything go wrong with the revenue service train.

The ET 403 is a train consisting of self-propelled cars, typically four to a consist, which includes two end cars and two interior cars. Consist size is limited to a total of 12 cars, 2 end cars and 10 interior cars. The train length limitation is current delivered through a single pantograph since the high voltage (15 kV, 16-2/3 Hz) is bussed to all cars.

One of the requirements of the DB was for the ET 403 to operate at high schedule speed within the existing signal system. This requires large accelerating and braking rates at high speed. Because of the curves and grades of their railroad, many speed changes at high speed (160 to 200 km/h) are needed. Design speed is 200 km/h (124 mi/h).

DB's philosophy is to use proven components in any new design. In fact, the DB requires that any new component developed for the railroad be tested in prototype form for at least a year and evaluated before being procured in large quantities.

The ET 403 had a slight tilt capability which was dismantled on the present three train sets. Apparently track forces increased as a result of the tilt mechanism; no explanation was given other than that the system was found to be unnecessary.

3.3 Track

Based on limited observation, it appears that curvature is similar to that in the United States, but maintenance is much better. DB indicated it would supply copies of the track standards.

3.4 Equipment Details

The train operates on 15 kV, 16-2/3 Hz. Like the APT, the 403 (like all DB equipment) uses an air blast primary circuit breaker. The DB appears to be concerned about the use of a vacuum interrupter due to its tendency to produce spikes which will cause serious difficulty with solid state equipment in the power circuits.

While the APT traction apparatus (transformer and smoothing reactors) is oil-cooled, only the transformer of the 403 is oil-cooled and the smoothing reactors are air-cooled.

The ET 403 is similar to, and a derivative of, the ET 420, which is a three-car MU trainset now used in commuter service. There are 300 ET 420 trainsets on order and 120 of them have been delivered and are in operation. The motors of the 403 are physically identical to the 420 but are rated slightly higher by use of different insulation and better cooling. The traction motors are truck-frame mounted and drive through quill and rubber couplings to the axle.

Acceleration averages 0.6 m/s^2, and a continuous tractive effort of 20 metric tons (22 short tons) is available to a speed of 100 km/h (62 mi/h). Each axle has a self-ventilated traction motor rated at 420 kW. The motor, which contains a 40-percent series field, is made by Seimens; they weigh 2 metric tons (4,410 pounds) each. Total field excitation can be varied from 90 percent to 41 percent.

AEG will make available all propulsion system electrical characteristics. Characteristics which were quoted in Germany include:

a. Transformer primary winding resistance 4.1Ω @ 75°C.

b. Transformer secondary winding resistance 0.011Ω @ 75°C.

c. Short circuit impedance of transformer 7.3 percent.

d. Choke or reactor inductance:

10 mH from 0 to 700 A

6 mH @ 1,200 A

2.7 mH @ 1,500 A

The propulsion system consists of two rectifier bridges in series which feed the four parallel, partially separately excited motors. Secondary windings on transformer include two 520 V windings for traction and a 1,000 V winding for propulsion. The catenary current of the 403 is 150 A per car at 125 mi/h. The propulsion system is scheduled for 600,000 kM between maintenance periods.

There is an automatic high-voltage coupling which should be investigated further. It permits use of only 2 pantographs on up to 12 cars.

The train resistance formula will be sent, which will allow evaluation of trainsets with a larger number of cars.

The brake system consists of dynamic brake blended with pneumatic operated disc brakes. The brake rotors are mounted on the wheel cheeks. Brake curves have been given to us. Loadweighing occurs for braking but not for traction. Dynamic brake resistor grids are located on the roof. There is also an electromagnetic track brake for emergencies and parking.

An additional feature is the use of the advanced Seimens train control and cab signal apparatus. For speeds between 160 and 200 km/h (99 and 124 mi/h), automatic train operation is in effect because of UIC rules. Speed is set by wayside control and transmitted by means of a wiggly wire which runs down the center of the track. The ATC responds by bringing the train to the required speed. The distance from the point where a speed restriction must be met is continuously displayed to the operator. The control devices in the cab are:

a. Automatic train control.

b. Inductive automatic train control.

c. Deadman control.

d. Train to wayside control with 36 kHz from train to tower and 56 kHz from tower to train.

With these controls the engineman has a very simple line display telling him his speed and another line display telling him if he is going to make his needed stopping distance. It is altogether a very well thought out system, emphasizing the safety features required to control a high-speed rail vehicle. Some portions of this system are available on 50 of the 1,960 locomotives which operate with series motors and a tap changer control.

The system looks 5,000 meters (3.1 miles) ahead of the train rather than the 2,000 meters (1.2 miles) of the conventional wayside signal system. An active display is provided for the engineman which tells him exactly how far he has in which to stop and which enforces a brake application if he fails to take the proper action. It is a continuous system in monitoring the speed of the train; in addition, wayside control of the train can also be accommodated. Braking distance from 160 km/h (99.4 mi/h) is 1,000 meters (3,281 ft) and from 200 km/h (125 mi/h) is 2,400 meters (7,874 ft). There are disc brakes and dynamic brakes, but no tread brake. Besides the monitoring equipment in the control cab, each of the cars has additional monitoring covering the functions of that particular car.

Auxiliary Equipment - Air-conditioning utilizes a dc motor fed from a rectifier bridge by the 1,000 V secondary of the transformer. The minor auxiliaries on each car are fed from a 20 kW static inverter. The total auxiliary rating is 75 kW.

General Truck Design - The trucks are fabricated steel, weighing a total of 12 metric tons (26,500 pounds) per truck, 4 tons (8,800 pounds) of which is comprised of the traction motor and gearing, while another 4 tons (8,800 pounds) is contributed by the wheel sets and journal bearings. Thus, the truck frame and its suspension apparatus proper weigh only 4 metric tons (8,800 pounds). The truck utilizes a rigid welded steel frame, with primary suspension by means of coil springs and two-leaf spring-type linkages which control the wheelset location. The traction motors are fastened to the truck frame, and the drive to the wheelset is by means of a Cardan shaft going through the center of the gear box. In response to questions, MAN responded that if a flexure plate (leaf spring) would fail, there is an auxiliary guidance device which maintains location of the wheelset.

Secondary suspension is by means of air springs. These are fastened directly from the frame of the truck to the car body without an intermediate bolster. The air springs are also used for load weighing for the brake system and are backed up by rubber emergency springs. Air springs are used in shear to swivel the truck because there is no bolster. In addition to the lateral spring rate provided by the air springs, the additional transverse rubber spring acts after 15 mm lateral displacement and gives a progressively increasing lateral spring rate.

The design of the truck is generally impressive, as is the attention to detail which has been given to it by MAN and the other German engineers. It is an evolutionary design, based on the truck used on the ET 420 train, which has been in service for some time. The truck of the ET 420 was developed for speed only up to 120 km/h (75 mi/h), and a relatively stiff guidance was used for the wheel and axle set in the x-direction. For higher speed, the ET 403 was provided with a softer wheel and axle set guidance in the longitudinal direction, which, in conjunction with the concave tread profiles which are used, permits a certain radial alignment on curves and enables side forces between rail and wheel to be reduced. Optimum values of the spring rates and damping of the primary suspension were based on a series of tests. A hydraulic damper is used to stabilize yaw between the truck and the car body. The literature mentions that hydraulic stabilizing devices were being tried out, which are intended to control truck rotation when running on straight track and on curves which may be negotiated at speeds above 160 km/h (100 mi/h). A hollow tread worn wheel profile is used. DB anticipates 180,000 to 200,000 kilometers (112,000 to 124,000 miles) between wheel turnings.

The cars originally had a tilt apparatus but it has been removed. This tilting apparatus used the air springs to achieve car body tilt by pumping up one side by means of an axle-driven air compressor.

Body Structure Design - The 130,000-pound car body is made of aluminum, utilizing long extrusions which are welded together. The team was given details of the types and the strength of the materials. The design is that of a load-carrying body with the extrusions forming the outer skin. The roof is made of pressed aluminum sheet. The buff strength of the ET 403 car is 330,000 pounds at the buffers and 88,000 pounds at the roof level. Vertical deflection of the body at center is 1 inch with a crush load. The four-car ET 403 train will carry 183 passengers; fully loaded, the train weighs 253.65 metric tons (280 short tons). Axle loading is 15.85 tons (34,940 pounds) per axle. Similar aluminum construction was used in the earlier ET 420 commuter equipment, but not with such wide extrusions.

Undercar streamlining is used at all positions along the body except at the trucks. The bottom cross section is curved. Components are mounted wherever possible on slide-in trays for ease of maintenance. Air cooling with a minimum of ducting is used by the undercar components. Air is brought in from the side into a filtered compartment and exhausted as quickly as possible after the heat transfer from thyristors, diodes, or heat exchangers.

The 403 equipment has sliding plug doors, which fit flush to the outside. A low and high level step are provided, both of which collapse and are very narrow. The cab accommodates two men.

The Germans had some interesting comments about aluminum body construction, claiming that repair of aluminum cars is "no problem" and that passengers fare better in a crash in aluminum bodies than in steel bodies because of the local crushing or "fuse" effect of the aluminum deflecting. DB maintains that aluminum cars have worse damage in the localized area of impact than steel cars do, but the extent of the damaged area is less than with steel. This claim was based on experience rather than on any tests; DB has operated aluminum cars for 15 years.

Ride Comfort - Although no data on general vibration levels were obtained, the ride from Augsburg to Munich could be classified as excellent. Of course, actual track conditions are unknown. Bounce, pitch, and yaw frequencies are 1.2, 1.0, and 0.8 Hz respectively, which are low enough to give an excellent ride.

Lateral Accelerations on Curves - As mentioned earlier, the Germans are not using a tilt system on the ET 403, which will limit the speeds on curves. The original banking system, which was developed by Knorr-Bremse, was designed for an angle tilt of ±4°. However, pantograph compensation must not have been included because it was reported that when the lateral movement was too great, the pantograph would lose contact with the overhead wire.

Interior Noise Levels - Firsthand information on the noise levels was obtained by measurements made with a sound level meter on the ride from Augsburg to Munich. Values obtained were 63 to 65 dB(A), 76 dB(B) and 88 dB(C), on a stretch of track where train speed was 200 km/h. Measurements were made in a first class compartment with the door closed (it was very quiet indeed). On the return trip measurements taken in the open car were 65 to 70 dB(A).

3.5 Technology Items

Because of the DB approach of using proven components, not much new technology (i.e., that not used on the ET 420) is involved. However, use of a series field/separately excited field combination motor may prove interesting in terms of United States consideration.

4.0 Swedish Equipment

4.1 Discussion and Meeting Highlights

September 16 - ASEA, Vasteras, Sweden

The principal contact at ASEA was Lars O. Nilsson, Manager of Traction Equipment, Transport Division. The agenda prepared by ASEA was very similar to that for the IPEEP visit made earlier in 1977. Several ASEA films were shown, including a briefing on the ASEA organization throughout the world, plus a description of their work on locomotives and mass transit vehicles. The IPEEP team also toured ASEA's DC and Large AC Machine Division, and the Electronics Division.

In Tillberga, the X15 train was inspected. The train is essentially a test bed for development of a tilt body system and tilt compensating pantograph. The car bodies for the X15 are from a 1948 X5 trainset. The goal of the development program is to optimize a train to run at high speeds, with low lateral forces on curves and with a minimum of track modification. ASEA and SJ are testing two tilting truck systems; one employs pneumatic and the other a hydraulic body tilting arrangement. The results of the work will eventually lead to an X2 train, which is at this point undefined.

Mr. Nilsson explained that some of the recent X2 (X15) information requested during the meeting went beyond the scope of the agreement originally made in the earlier visit, and that more data would require additional agreements. When the group requested Rc4 propulsion system characteristics to aid in understanding the APT traction system, Mr. Nilsson stated that such data must be obtained from the Electro-Motive Division of General Motors, who is the United States representative.

4.2 General Status

The X2 represents a design which was proposed to the Swedish Railways a few years ago; it has not been bought at this point. The X15 is a test bed, and the tilt system which ASEA is testing appears to be far from a developed system. However, ASEA does have a truck designed without tilt mechanism which will be used on a new order being built for the Queensland railroad in Australia. In this version, air springs are used as the secondary suspension directly between the truck side frame and the body.

4.3 Track

Railway length is 7,000 miles. Electrification is 15 kV, 16-2/3 Hz, all interconnected with no phase breaks. The maximum present speed is 140 km/h (85 mi/h) with future plans for some 160 km/h (95 mi/h) operation. Axle loading limitation is 25 metric tons (55,000 pounds) on the main lines and 16 to 17 metric tons (35,300 to 37,500 pounds) on branch lines.

4.4 Equipment Details

Maintenance periods anticipated are 1.2 million kilometers (746,000 miles) for overhaul. As in the case of BR and DB, the vacuum interrupter is not used and the air blast circuit breaker is used for primary protection. ASEA's philosophy is to use modular equipment and quick disconnect for ease of maintenance, extensive fault monitoring, and employment of test points in the traction equipment.

The ASEA slip-slide control is a new development. It utilizes a sensor which listens to axle noise during the creep stages of the slip-slide. Power and/or brake is removed for correction as required, rather than removing either completely as is done in the United States. A 15- to 18-percent increase in tractive effort capability has been observed. ASEA has 300 thyristor locomotives on order of which 190 are in service.

No information was available on the tractive effort/amp/speed characteristics of the traction motors (or electrical parameters) because the motor is not designed. During the tour of the electronics shop it was mentioned that Rc4 traction motor fields are rated at 300 A at 50 V and armatures at 2,000 A at 900 V.

Items Relating to Rc4 Locomotive - ASEA would not give any detailed information on Rc4 characteristics because of the present negotiations on the light locomotive with Amtrak. They are bidding through licensing arrangements with GM and suggested that we contact GM for such information.

Suspension Systems - The three-car X15 train uses two types of tilt actuation. The end cars have the original pneumatic mechanism and the center car has a newer system which uses hydraulic actuators. The design tilt is ±8° and radially steered axles are considered necessary. The intent is to utilize tilt and steering to achieve a speed improvement of 35 to 60 percent on curves. This is with only modest tract improvements.

The trucks now used on the center car of the three-car trainset are of a still-unproven design and the tilting mechanism is entirely new. It appears to have a very high center of rotation, with a great deal of apparatus protruding up into the car body.

The new truck has a chevron-type primary suspension which ASEA considers to provide radial steering. ASEA states that the steering feature will, on a given speed, reduce lateral track forces by 40 percent. SJ track standards were requested.

The roll center of the tilting mechanism is a little above the center of gravity. Speed limits are based on a 0.05 g lateral acceleration for passenger comfort. There is still no decision as to whether a hydraulic or an air-activated tilt mechanism will be used.

The truck which ASEA will use for the Australian cars has a primary rubber chevron suspension, and then a rigid side frame with air suspension mounted in a relatively conventional fashion on the top of the side frame between it and the car body. Howwever, in the new tilt version using a large curved-segment bolster, this bolster is interposed between the truck frame and the car body, and the air springs are then mounted on the top of the bolster. It was stated that "hydrostatic bearings" are used to support the car body bolster on the truck bolster. A hydraulic cylinder is used to rotate the car body bolster relative to the truck frame. An interesting fact about this truck was that it has a yaw damper which is about 8 feet long between the truck frame and the carbody, along the side of the car.

The pantograph is fastened to the top of the car body and has a special linkage to move it relative to the top of the car body to keep it centered over the track. A ±8° tilt is used, which allows the attainment of a 45-percent overspeed in curves. The hydraulic design is the second pantograph tilt compensation design: The first design had cables connecting the pantograph to the truck frame, and the current version has a hydraulic cylinder between the top of the car body and the pantograph. To accommodate the relatively massive bolster elements for the tilt mechanism, ASEA has had to locate the air springs up inside of the car body. The roll center for the train is "about seat height, that is, the top of the cushion."

ASEA has developed a dynamic simulation program which includes 4,000 cards and requires a 50 k memory computer. The program uses 36° of freedom. Output includes information on ride quality, track forces, and safety (overturning and wheel climbing). A paper describing the model will be sent in about 2 months when published.

The first test of the model was on the radial steered truck test project. Test measurements versus calculated values agreed to within 10 percent. Radial steered trucks have been tested from 100 to 240 km/h (62 to 149 mi/h) and were found to reduce track forces by 40 percent. (The test vehicle was not identified.)

4.5 Technology Items

a. Tilt Body Pneumatic - Avoids use of high pressure hydraulic fluid but response time may be too long. Higher speed in curves.

b. Tilt Body Hydraulic - Higher speeds in curves.

c. Radial Steered Trucks - Reduction of track forces.

d. Oil-Cooled Thyristors - Reduction in propulsion system weight. More uniform heat transfer.

e. Oil-Cooled Reactor - Reduction in propulsion system weight. More uniform heat transfer.

f. Separately Excited Motors - Better acceleration characteristic at high speed.

g. Solid State Converter - A new development which would be used on the Rc locomotive is a 100 kVA solid state auxiliary supply which utilizes single phase to produce three-phase. It was approximately 7 ft x 4 ft x 5 ft in size.

5.0 French Equipment

5.1 Discussion and Meeting Highlights

September 17, 18 - Weekend

September 19 - Alsthom, Belfort, France

The principal contacts at Alsthom were:

Mr. Guth, Principal Engineer, Belfort Plant of Alsthom-Atlantique.
Mr. Jean-Marc Chatelain, Assistant Chief Engineer for Overall Studies, Alsthom, Paris.
Mr. Jean-Claude Brimont, Group Coordinator for TGV, Alsthom-Atlantique, Paris.

The IPEEP team was briefed by Mr. Chatelain on the design philosophy of the TGV. He explained that the old electrification system in France which was put in during or just before World War II, was 1,500 V dc. Later, 25 kV 50 Hz ac was installed. The TGV was designed to run on both systems. All of the 87 trains being built for the Paris-Lyon line will be ac plus dc. Later in the day, the shops were visited and fabrication of the TGV power cars was observed. In response to questions on cost, Alsthom quoted a budgetary price for the TGV trainset as 20 million Francs based on an 87-train order (as currently planned for SNCF).

Mr. Chatelain mentioned that the TGV.001 test program will be completed by the end of this year.

Alsthom is a large builder of locomotives and cars; they build all but minor components, which are procured from vendors. They are also a large manufacturer of electrical equipment for power generation and distribution facilities. Alsthom can produce 150 to 200 locomotives per year, and has built more than 4,000 locomotives. Both electric and diesel-electric locomotives are exported to over 45 countries.

Electric locomotives range between 1,200 and 8,000 hp at the following voltage/frequency combinations: 25 kV/50 Hz, 15 kV/16-2/3 Hz, 1.5 kV dc and 3.0 kV dc. Locomotive types are BB, BBB, and CC for metric, standard, and large gauges. Diesel-electric locomotives built by Alsthom range in power between 800 and 4,000 hp as BB, BBB, and CC types.

5.2 General Status

There will be 87 trainsets of TGVPSE built for the new Paris-Lyon line, which will be completed in 1981. All of the trainsets will utilize 25 kV, 50 Hz for basic propulsion, and all will also be capable of operating on existing 1,500 V dc systems in the vicinities of Paris and Lyon. Ten trainsets will have a 15 kV, 16-2/3 Hz additional capability for operation into Switzerland. Two prototype electric trainsets are being built for tests.

The TGV.001 (gas turbine test train) was used to test high-speed technologies for incorporation into the TGV electric. Many tests were run at speeds from

260 to 280 km/h (181 to 174 mi/h) with a record speed of 318 km/h (198 mi/h) reached. The TGV.001 has accumulated between 300,000 and 400,000 km of running with an estimate of 3,500 km of running above 300 km/h. The French believe that 260 km/h (161 mi/h) is practical for revenue service operation.

The TGV electrics are presently in the final design phase with delivery of the first two trainsets scheduled for late 1978 or 1979. One can expect that not all parameters of the design are as yet complete.

The TGV is not a tilt-body train, although it is articulated. Six power trucks are used, three on each end of the train, with interior cars connected by articulated couplings. A consist made up of one power car, eight intermediate cars, and one power car is anticipated at this time. The TGV will experience up to 0.1 g lateral force on curves; this is equivalent to 6 to 7 inches of unbalance, although the normal SNCF unbalance on conventional rail is 3 to 4½ inches.

The existing rail line between Paris and Lyon follows rivers with many curves; it has heavy traffic and is in bad shape. Thus, requirements for a new line were established which would cut the journey time from the present 3 hours and 44 minutes to 2 hours. The decrease in journey time is expected to increase annual patronage to 17 million passengers per year. (Present rail patronage was not immediately available, but Alsthom will find the answer and send the information.)

Basic information on the new line is as follows:

a. Distance will be decreased from 512 to 440 km.

b. Top speed of line to be set at 350 km/h (217 mi/h), although TGV is expected to run at maximum speed of 260 km/h (161 mi/h).

c. The line will have more and steeper grades than the existing line. Maximum grade of new line is 3.5 percent as compared to 0.8 percent on present rail. Low speed curves would be limited to 800 m radius (2.1°).

d. The new line is expected to serve the population areas of Paris with 10 million people and Lyon with 10 million people (in surrounding cities) for a total of 40 percent of the population of France.

e. Normal headways on the new line will be set at 15 minutes with peak headways of 4 to 5 minutes for heavy business travel near weekends.

f. Fares on the new lines are expected to be the same as the old line on a per kilometer basis.

5.3 Track

SNCF track is generally well maintained with good cross alignment and rail profiles. It is among the best in Europe.

5.4 Equipment Details

Propulsion System - The main electrical supply of 25 kV, 50 Hz from Paris to Lyon is expected to be regulated between 22.5 kV and 27.5 kV. The line is sectionalized by phase breaks and eight substations are used over the entire route. South of Lyon the TGV Electric will also be able to operate on 1,500 V dc with reduced performance to the Riviera, and 15 kV, 16-2/3 Hz into Switzerland.

The dual voltage, dual frequency requirement for the TGV means that switching will be necessary. A controlled rectifier is used for ac propulsion control, and a chopper is used for dc propulsion control as well as dynamic braking under all cases. Components are switched in such a way that the same components with different circuit configurations are used for the controlled rectifier, power chopper, and brake chopper.

The traction motors are series type with a 12-percent field shunt permanently in the circuit. This provides a slight phase shift between armature current and field current, and is used to assist commutation at higher motor speeds by reducing ripple. The rating of a traction motor is 530 A; it is a 1,500 V dc (1,410 V rms) self-ventilated motor. Field and armature resistance is 0.12 to 0.015 ohms. Motors are never used at full voltage, even on dc supply.

The TGV will use all class H insulation with an operating temperature of 180°C. (Our experience with class H insulation on Westinghouse motors used in Metroliners 815 and 816 was unsuccessful and we had to return to class F. The French claim this was due to unevaporated solvents and that the problem has been solved by using class H resins without solvents.)

The transformer is 1,410 V ac on the traction secondaries (rectified value 1,160 V dc). It is silicone oil-cooled for use in tunnels, although mineral oil is normally used in transformers by SNCF. The smoothing reactor is also oil-cooled within the same container as the transformer. Inductance is quoted at 3 mH with a 5 to 10 V drop at 1,000 A (0.005 to 0.01Ω). Chopper control of the dynamic brake is new on the TGV, but the main power conditioning system is used on a 350-locomotive order. Approximately 120 locomotives of this type are in service. The ratings of the propulsion equipment are set as follows in the table below (based on a per motor rating).

TABLE 2. PROPULSION EQUIPMENT RATINGS

Component	Rating (A)	Percent of traction motor rating
Traction motor	530	100
Smoothing reactor	480	90
Transformer	450	85

Weight reduction was a prime consideration in establishing ratings. Only about 1 hour of actual high-speed operation is planned using the transformer (for example, running on the 25 kV, 50 Hz line). The transformer is therefore derated by 15 percent. The rating of the smoothing reactor is different from that of the motor because the motor is self-ventilated with ratings based on high-speed running. The reactor is oil-cooled on a continuous basis.

An air blast high voltage disconnect is used to clear the pantograph from the transformer. It is operated both from the main air supply and a small backup compressor specifically for the breaker. A drying agent (aluminum oxide) is used to insure the use of anhydrous air. Thyristors are used to disconnect the loads with backup mechanical switches for security of personnel. The mechanical switches provide complete disconnect of the traction circuits.

The Rc train resistance formula used by Alsthom to estimate TGV train resistance will be sent to UII.

Braking System - There are two friction brake systems using discs. It is possible to stop in 1,380 meters (4,530 feet) from 180 km/h (112 mi/h). The system is air-operated. Dynamic brake blending occurs in normal operation; however, in the event of a failure the friction brakes can be used to stop the train. The decision about whether to install a track brake has not yet been made. It may be omitted in order to keep the unsprung weight to a low level. The emergency braking rate is 1 g; the full-service rate is 0.068 g. A stopping distance of 6,300 meters (3.9 miles) will be required in full service from 260 km/h (161.6 mi/h).

Auxiliary Equipment The most important feature of the auxiliary system is the use of a 450 kVA dc to three-phase converter. There is one converter in the car adjacent to each locomotive.

The converter on the front car feeds auxiliaries on itself and three cars adjacent to it while the converter on the rear car feeds its own auxiliaries and those on the remaining three cars. In the event of failure, one converter can feed all eight cars. The auxiliaries which are fed include air-conditioning, battery chargers, blowers, and various motors. A prototype inverter has been built and will be tested on the prototype cars.

An auxiliary winding on the transformer feeds a rectifier which in turn feeds the locomotive air compressor, car heaters, and the converter. The converters supply an output to a transformer in order to isolate the auxiliary winding; the transformer also improves the waveform of the converter. A 72 V dc train line with batteries is fed from the battery charger and used to maintain continuous lighting as the train moves through regional sections and the respective phase breaks.

General Truck Design - The design of the truck for the TGV is an evolutionary design based on the Y226 truck. The Y226 was tested on the electric test car (Z7001). The electric version (TGV-PSE) will have locomotives with separate BB trucks rather than the articulated power trucks of the TGV.001. In addition, the intermediate car directly next to the locomotive will also have a conventional powered truck at one end, but will share a truck at the other end with the adjacent trailer car. For a 10-car trainset, therefore, 13 trucks will be used and of these, 6 will be powered. The articulated trucks will not be powered, but the three nonarticulated trucks at each end of the train will be.

The trucks are of the rigid frame design. Radius rods are used to control wheelset location, and the primary suspension is achieved by means of coil springs and hydraulic shock absorbers. The truck frame is composed of welded side frames joined by a tubular crossmember at each end -- at least for the power truck. Its motors are suspended from the truck frame and drive the wheelset through a Cardan shaft which actually surrounds the axle of the wheelset. This design is different from that of any other truck. The arrangement of the secondary suspension and provision for transferring tractive effort from the truck through the center pin pivot and into the body bolster also appear more complex than in other truck designs. The secondary suspension consists of two Sumiride air suspension springs. Worn wheel profiles are used. SNCF and Alsthom view an active suspension system as complicated and expensive for the benefits provided. SNCF normally operates at 160 to 180 km/h (99.4 to 111.8 mi/h) on most routes without active suspensions for tilting.

Structure - The locomotive body is a self-supporting structure made of semistainless steel. The nose incorporates a protection shield intended to resist an effort of 70 metric tons (15,400 pounds) distributed evenly at the level of the upper waistline. The trailer body is semistainless steel stressed skin monoblock tubular construction. The folded steel frames of the articulation assembly are provided with security arrangements that can sustain tractive efforts of 100 metric tons (220,460 pounds).

The proposed configuration of the electric TGV is a 10-unit trainset, which would weigh 694,000 pounds empty. According to this, the buff load would have to be 800,000 pounds by AAR standards. The buff load to which the TGV will be proof-tested is 440,920 pounds per locomotive and 330,690 pounds for the trailer cars. If a shorter consist were used, the TGV power car would meet the 400,000-pound minimum AAR static buff load requirement, but the passenger car would not.

Interior Noise Levels - The measured levels in the passenger compartment at 137 mi/h were 58 dB(A) and 75 dB(A) in the driving cab. Sound levels at 300 km/h (or 186 mi/h) were 64 dB(A) in the passenger compartment.

5.5 Technology Items

a. Articulation - Lightweight for high-speed running.

b. Chopper Controlled Dynamic Brake - Chopper required anyway for dc power control.

c. Oil-Cooled Smoothing Reactor - Lightweight for high-speed running, better heat transfer.

d. 450 kVA (dc to 30 ac) Converter - Probably eventual lightweight advantage.

6.0 Swiss Equipment

6.1 Discussion and Meeting Highlights

September 20 - Travel Day (France to Switzerland)

September 21 - SIG at Neuhausen

Principal contacts at SIG were Messrs. Bernhard Huber and Paul Reithaar. The meetings were begun with a slide presentation which described SIG's Wagon Works and a tour of the shop area.

During the technical discussions, Mr. Huber stated that at present four Type III cars have been built to accommodate SIG's tilt system, but the system has not been installed in other Type III cars because of the price. Swiss Federal Railroads is now in a deficit situation and has elected to do without new investments. Mr. Huber stated that the tilt system would represent only about 10 percent of the car's total price.

6.2 General Status

The Swiss, in the Type III coaches, are making a serious attempt at improving the speed of trains on curves. There have been 68 Type III cars built, representing the latest edition of the Swiss Federal Railroad's standard passenger car. A standard truck without active suspension is used at present, except for four specifically equipped cars which are about to start revenue tests. Their efforts in this particular area will shortly be evaluated and the results of this test service will be important for IPEEP to monitor.

Revenue service tests will start in November 1977 for the four cars with the tilting apparatus. They will be shipped to Norway in January for cold weather tests. The four cars include a first class coach, a second class coach, a diner, and a combined first class coach and baggage car. Average mileage on these cars is around 300,000 km (186,000 miles) at this point.

6.3 Track

From a brief ride on one TEE-train, it appears that Swiss track is typical of that found in mountainous countries and has curves tighter than those in the United States. Maximum speeds in Switzerland are limited to 140 km/h (87 mi/h). General maintenance levels of the track appear to be better than ours.

6.4 Equipment Details

Because cars are unpowered trailer cars, motive power discussions with SIG were not applicable. Braking is by disc brake and information on brake capability was provided previously.

General Truck Design - The general truck design includes a rigid steel box frame with primary suspension by helical coil springs (steel) or rubber springs in conjunction with links, and secondary suspension by means of Flexicoil springs which are nested low in the edge of the rigid frame to maintain the space needed for the steps directly over the springs. Primary damping is by friction in the main pivot bearing, and secondary damping is by hydraulic dampers in the vertical and lateral direction. Worn wheel profiles are used.

The static axle loads are the lightest of any vehicle being evaluated: 9 to 11 metric tons, or a maximum of 2,440 pounds per axle. The unsprung mass is 2,457 pounds per axle.

Design Speed - The maximum design speed is only 140 km/h or 87 mi/h, which puts these cars at the low end of the speed list for the vehicles being considered. They would, of course, be applicable for those corridors not equipped for cab signaling, where speed is limited by the cab signal requirement of 79 mi/h.

The car body is constructed of aluminum, including extrusions and sheet which are automatically welded together. A car body stiffness, in terms of vertical bending frequency, of 7.5 Hz was quoted, which is low. This value compares with values between 10 and 15 quoted for other cars. There is no end door on the cars, just a compartment door diaphragm; this system has been used on TEE-trains. The car body itself weighs only 4.5 metric tons (9,920 pounds). Automatic couplers are applied to this equipment, although they will probably not be fully utilized by the Swiss.

Information on the buffload capability is somewhat contradictory, but it appears that the draft gear has been tested at something between 225,000 and 390,000 pounds; either value is below AAR requirement. Collision posts and anticlimbers are not used in the Swiss car body. A truck-to-car body attachment strength of 1.5 g vertically and 3.5 g in shear is quoted.

Tilt Mechanism - The Swiss engineers have managed to design a very compact tilt mechanism into a truck which can be used with or without the tilt mechanism. It utilizes a curved car bolster-type element resting on two rollers of the truck bolster. This truck bolster is above the secondary suspension. A hydraulic actuator is used on each truck to provide the banking action, which provides a maximum of ±6° tilt. The truck design was complicated by the railroad requirement that the platform loading steps be located directly over the center of the truck, an area which in most trucks is occupied by the secondary suspension. This truck is being supplied to the railroad without the tilt suspension.

The tilting apparatus can be installed merely by changing the bolster and adding a few other electronic and electrical components. Because of the increase of weight and the hydraulic unit, the center of gravity will actually be lower, although there will be no dimensional changes in the car body itself or in the truck.

In a train the preceding car is used to signal the next following car and 1.8 seconds are required to tilt from 0 to 6 degrees. Tilting is started 0.1 seconds after the signal is received. An emergency pump is provided to take care of failures in the system, and the driver is also signaled in the event of failures so that speed may be reduced. The tilting apparatus, as usual, provides only for better comfort to the passengers, allowing the higher speed without danger of overturning. There are some current problems with the Honeywell accelerometer used as a sensor. This is expected to be overcome during revenue tests. A worn wheel contour is used.

General Vibration Levels - Ride quality characteristics were given as follows: vertical ride index is 2.6, lateral index is 2.2. This is at an average of 140 km/h on level tangent track.

Lateral Accelerations on Curves - Inclusion of a tilt system will allow unbalance of 6° to be taken without inducing uncomfortable lateral accelerations to the passengers.

Interior Noise Levels - Test data shows values of 64 dB(A) at 125 km/h (78 mi/h) on open level tangent track. Thick insulation is used in various parts of the car and was evident in the cars under construction during the tour of the car assembly area.

7.0 Italian Equipment

7.1 Discussion and Meeting Highlights

September 22 - Fiat, Milan, Italy

The principal contacts at Fiat were:

Mr. Vincenzo Milanesio, Commercial Director, Fiat Rail Operations
Mr. Lelio Casale, Vice Commercial Director, Fiat Rail Operations
Mr. Oreste Santanero, Chief Engineer, Fiat Rail Operations

The technical team entered into an intensive discussion with Mr. Santanero on the technical aspects of the train. Mr. Marchetti, of the IPEEP team, acted as interpreter for the team.

September 23 - Ride on Pendolino (Rome to Foligno)

On Friday, the team rode the Pendolino from Rome to Foligno. The train rode very well, and the tilt system enabled the trip to be made at very high speed. There was some noise in the passenger car, coming from under the floor. The noise resembled mechanical tapping sounds and hydraulic pumps, and was quite noticeable on occasion. Overall impression of the train was very favorable.

7.2 General Status

Presently, there are only two Y0160 Pendolinos, one in Italy and one in Spain. The trains have been in service 14 months, and the Italian train has 200,000 kilometers on it. The Italian State Railways (FS) version is designated the ETR 401. There is not much data on operating and maintenance costs as yet.

The Pendolino is not a high priority program in Italy, but the program in Spain will involve 20 trains built in Spain under license.

The train is a multiple unit set (MU) but not articulated. The four cars consist of two married pairs. Lightness in weight and softness of truck springing have been carried to a point approaching aircraft design. Longitudinal strength of the car is obtained by longitudinal tubular steel members running within the inner and outer skins of the car.

It is apparent that the train is still under development, although one train is operating in Italy and one is on demonstration duty in Spain. The Spanish train is of wider dimensions and can accommodate a two-plus-two seating arrangement. Both versions are built to operate on a 3 kV dc system.

Future plans for the ETR 401 are uncertain in Italy. The FS has allotted $17 million for all railroad improvement plans for the next 10 years and the ETR 401 is low on the priority list. Of the $17 million, one-third is for rolling stock, of which most is designated for replacing present old locomotives and coaches to keep people moving.

Future plans in Spain are calling for an order of 25 trains with some modification. Since maximum speed is limited to 140 to 160 km/h (87 to 99 mi/h) in Spain, no speed control is necessary. Fiat indicated that Spain wants the tilt capability more than Italy does; however, Spain does not want the ATC feature.

7.3 Track

Based on the limited train riding in Italy and information obtained at the meeting, it appears that Italy's track is comparable to or better than track in the United States in terms of overall condition, but it has more curves. Fiat indicated that certain routes need the tilt feature, especially in the mountains, and added that particular high-speed routes needing tilt were Milan to Rome via Bologna and Florence.

Normal superelevation on the Italian railroads is 160 millimeters (6.3 inches). Once again, the team asked for and was given assurance that it would be given track information which can be used to compare FRA track standards with those of the Italian railroads.

7.4 Equipment Details

Propulsion System - The ETR 401 is a 3,000 V dc electric train. The design speed is 250 km/h (155 mi/h). The inward axles of each truck are powered by dc motors which are connected two in series. The control is rheostatic. A pair of cars is required for traction control which operates as follows:

a. Motors on the pair of cars are connected in series and the rheostat control cuts out resistance until full voltage is reached on the motors.

b. Motors are then switched into two parallel pairs and the rheostat is again used to cut resistance until full voltage is reached on the motors.

c. The separately excited field control is used to reduce motor field current until the desired speed is reached.

Motors are centrally hung on the bodies and drive through Cardan shafts to a 90° gear box mounted at the center of the axles.

Cab signals and speed control will be utilized in Italy for high-speed operation. This applies to construction of new lines and improvements to old lines.

The body and mechanical parts are made by Fiat, including the tilt equipment. Brake equipment is made by WABCO. The electrical traction equipment is made by Ajgen-Ansaldo, a government firm. The electronic portion is made by Ajgen and traction motors and gears by Ansaldo. Electrical equipment for cab signals is made by Ercoli-Merelli, a private corporation. Fiat does not have much experience with electric traction although they have manufactured some subway equipment. Most of their experience is with diesel-electric traction.

There is no maintenance information available yet, although the train has been operating in Italy for 14 months. A maintenance manual is being prepared and will be sent to UII as soon as it is in print. The cost of maintenance and the man-hours required at given periods are not fully known. Purchase cost of the Spanish trains is $4 million per 4-car train for 20 trainsets.

Total train kW is about 2,900 in short-time condition. The undercarriage of each car is completely full of apparatus and there is no room for the installation of other equipment which might be required to adapt this train to an ac supply. For test purposes, it might be possible to put a transformer inside one of the cars to allow it to operate on the 25 KV, 60-cycle system. Such a modification will be simulated for IPEEP performance simulation.

Brake System - A WABCO brake control is used. The pneumatic disc brakes utilize two discs per axle. The rotors are axle-mounted rather than the wheel cheek type. Dynamic braking is also used in conjunction with the track brake. A magnetic track brake is also used in the event of sliding wheels. This is necessary because of high speeds.

Dynamic braking is obtained from the drive motors which are separately excited, and field can be supplied either from the catenary or a battery supply. This insures the availability of dynamic braking even in the case of lost catenary.

Automatic train control with blended braking is provided.

Auxiliary Equipment - The Italian Y0160 uses a motor alternator to provide three-phase power at 320 V, whereas the Spanish unit has a static inverter of 150 kW for the same function of supplying the auxiliaries.

General Truck Design - In addition to the basic tilt system, the truck has two major features. The first is a complete lateral air suspension system which keeps the U-shaped bolster centered relative to the side frames. Air cylinders are arranged laterally between the side frames and an extension (fore and aft) at the base of the bolster. Mr. Santanera explained that these four pneumatic springs have a pressure which is a function of speed, with a maximum pressure being 6 atmospheres. He chose this method of centering laterally rather than optional methods of simply allowing more lateral clearances or adding springs which would increase the lateral stiffness. By using an air spring suspension, of course, he can maintain his centering position and still maintain the same spring rate or natural frequency.

A basic concept of the truck is the fact that the frame itself is articulated -- that is, instead of having two side frames connected by two cross frames welded together in a rigid unit (as is the case in most truck designs), each side frame is connected to the opposite side frame by a lateral member which terminates in a ball and socket at the other side frame. This, in effect, creates a diagonal axis through the truck, which allows half of the truck frame to "hinge" relative to the other half. The advantage is that load equalization is improved. That is, when any wheel is raised by a bump in the track it does not affect the loads carried by the other wheels, at least not as much as would be the case if the truck frame were rigid.

A final comment about the truck design is that Fiat has been experimenting with the use of the lateral air cylinders or some other lateral system actually to steer the trucks; this presumably means moving the axles radially relative to the side frame. Fiat is still continuing to experiment with the system and did not want to venture an opinion as to its future or value.

Static axle loads on this vehicle are very low at 11.25 metric tons (24,795 pounds).

Structure - The bodies are load-carrying structures made of "light alloy" (probably steel). The basic framework of the body consists of two vertical structural rings straddling each truck (lateral) centerline in a lateral plane to which the sides, roof, and floor frame are fastened to make a load-carrying tubular structure. These rings take the loads from the attachment of the body to the upper end of the tilt actuators. There are two C-shaped vertical structural members located in a longitudinal plane and extending forward from the circular members over the truck to the front of the car. Door openings, which might otherwise weaken the structure, are placed at the extreme ends of the coaches. Altogether, it is a rigid body structure.

The train is designed to meet the requirements stated in FICHE UIC 567-1, which are probably similar or identical to the UIC specifications in section 2.4 of this report.

The Pendolino tilt mechanism used on the cars without pantographs is quite different from the cars with pantographs. In fact, two basically different trucks are used, one (on pantograph cars) having steel coil springs and the other (on nonpantograph cars) having air springs. In the pantograph equipped cars the secondary suspension consists of two large coil springs mounted on the side frames and a large U-shaped bolster is mounted on these coil springs. The body is suspended from this secondary bolster by two or four links, and there is a series of circular slots or guides in the bolsters, into which are fitted rollers which further guide or take forces into the body structure.

The pantograph mechanism is attached to the top of this bolster, so that it is isolated from vibration by the secondary suspension but does not roll with the body. There is a chamber inside the body to support the portal-type mechanism which in turn supports the pantograph. Also in this body cavity are two long, nearly upright cylinders with gimbal mountings at the top end. These hydraulic cylinders are used to rotate the body relative to the bolster.

The tilting system is basically pendulous and would operate even without the use of an active system, although it does utilize a power banking in order to assist the pendulum to achieve equilibrium condition a little quicker than would obtain naturally. A gyroscope is used to sense the beginning and end of curves (spirals) while the accelerometers on each car keep the system at its required level of unbalance and equilibrium to the passengers.

The gyroscope and electronic package on the lead and end cars are actuated by the spiral into the curve. This results in a train line signal which allows the curve to be felt by individual accelerometers on each of the cars, and which actuates the tilt via an electronic package (volume 1½ ft x 1½ ft x 1½ ft). Lateral compensation is provided by the suspension. Air springs vary pressure to bring the center of gravity toward the inside of the rail.

Two of the most important features of the ETR 401 are its tilt capability and light weight. Extreme care was taken to lighten axles, body-mount motors, and lighten body in order to run at a top speed of 250 km/h (155 mi/h). On present lines, top speed is usually restricted by items other than curvature.

General Vibration Levels - The team had a chance to experience the ride firsthand on the trip between Rome and Foligno. The ride was thought to be very good indeed at the start of the trip, but that was on the new track. After leaving it for older track the ride was not so good as previously; however, it is felt that the banking system did an excellent job. There were, however, numerous whirrs, grunts, and creaks noticeable in the car, some while sitting in the seat and some while walking back beside the area where the tilt mechanism and pantograph mechanism are located in the body. In general, the ride can be classified as good, although a ride such as this points out the frustrations of trying to rate the ride when the track condition is not known. The team's general impression is, however, that it is much too responsive to small irregularities in the track. We did not notice any particular improvement in overall ride quality, although curves were negotiated at higher speeds than would have been possible without the active suspension system, while permitting the same level of passenger comfort. The system was much too "busy" trying to overcome the minor track irregularities and to compensate for much more than was necessary.

Lateral Acceleration on Curves - As mentioned above, it was thought that the roll system did an excellent job of compensating for unbalanced speed on curves.

Interior Noise Levels - The team asked what the interior noise levels were, but Fiat would not give a direct answer, saying only that is was no higher than 60 dB(A) at any speed.

7.5 Technology Items

a. Tilt - Higher speeds in curves, thus reducing overall schedule speed.

b. Body Mounted Motors - To lighten axle loading for high-speed running.

c. Lightweight Body Construction - Aluminum for light weight, which is necessary for high-speed running.

TRIP REPORT

IPEEP PROPULSION TECHNOLOGY SURVEY IN GERMANY AND SWITZERLAND

JUNE 12-22, 1978

R. A. Uher
Deputy Director
Transportation Research Institute
Carnegie-Mellon University

and

J. W. Marchetti
J. W. Marchetti Co.

DECEMBER 1978

NOTICE

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FOREWORD

This report summarizes the information on advanced propulsion systems obtained on a visit to the following firms in Germany and Switzerland:

1. Brown Boveri Co., Oerlikon, Switzerland
2. Brown Boveri Co., Mannheim, Germany
3. AEG-Telefunken, Berlin, Germany
4. Siemens, Erlangen, Germany

The visits took place during June 12-21, 1978.

The trip was taken under the auspices of the Improved Passenger Equipment Evaluation Program (IPEEP), was technical in nature and the delegation consisted of the following persons:

M.C. Gannett - Federal Railroad Administration (part-time)
J.A. Bachman - Unified Industries, Inc. (part-time)
J.W. Marchetti - J.W. Marchetti Co.
R.A. Uher - Carnegie-Mellon University

This report has been sent to the firms visited for their review. Their comments have been incorporated into the final version.

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June 12-22, 1978

1.0 EXECUTIVE SUMMARY

Under the auspices of the Improved Passenger Equipment Evaluation Program (IPEEP), a delegation was sent to Germany and Switzerland to obtain the latest information on advanced propulsion systems developed in those countries. Visits were made to three firms: Brown Boveri Co. (BBC), AEG-Telefunken (AEG) and Siemens.

The IPEEP delegation was technical in nature and consisted of the following persons:

M. C. Gannett - Federal Railroad Administration (part time)
J. A. Bachman - Unified Industries, Inc. (part time)
J. W. Marchetti - J. W. Marchetti, Inc.
R. A. Uher - Carnegie-Mellon University

The dates and places visited by the delegation include:

June 12-13 - BBC-Orelikon, Switzerland
June 14-15 - BBC-Mannheim, Germany
June 16-17 - AEG-Berlin, Germany
June 21 - Siemens-Erlangen, Germany

1.1 Visit to BBC - Oerlikon, Switzerland

The purpose of the visit to BBC-Switzerland was to review advanced AC drive development for diesel and electric traction. The principal information which resulted from this visit is:

1. The first BBC-Switzerland experience with AC drive equipment began in 1972 with a power car of the BE 4/4 series which was converted to AC drive to run under a 15kV, 16 2/3 Hz catenary.

2. BBC-Switzerland has also delivered 6-Am 6/6 diesel-electric locomotives with AC drive transmissions consisting of six three phase AC induction motors.

The locomotive unit has two inverter units, each supplying the three motors of one bogie connected electrically in parallel. These locomotives are peculiar in that they were specified to be capable of accelerating a 771 ton (700 tonne) train to 12 MPH (20 km/h) on a 2.5% grade as well as be used for yard humping and switching service. The inverters are liquid cooled.

Although slip control is automatic on an individual axle basis on the Am 6/6 it was necessary to incorporate a torque reduction capability should all six axles or all axles on one bogie slip. When the speed differs too much between bogies, or a speed change is too high, the torque is quickly and momentarily reduced. Generally the torque reduction is not noticed at the train coupling and lasts approximately 50 ms.

Because of the design of the locomotive traction equipment, maximum tractive effort can be held continuously at any point on the tractive effort speed curve including standstill.

The six Am 6/6 diesel-electric locomotives had some difficulty during the experimental period. Approximately 30 thyristors had been lost. The locomotives are now running trouble-free after improvements. Accumulated distance as of June, 1978, was 6835 mi (11,000 km) / locomotive.

3. For the type of AC drive transmission used for the Am 6/6, axles driven from the same inverter are required to have wheel diameters matched within .08 inch (2mm) in order to avoid wheel/rail machining in service to achieve the correct diameter. (It should be noted that zero to full torque is developed within 2% motor slip and this is the reason for the strict requirement on wheel diameter.) Wheels on separate bogies need only to be true to 20 mm.

4. BBC-Switzerland has made a proposal for the four quadrant controller - AC drive 4 MW main line locomotive (Re 4/4UR) for the Swiss Federal Railway. The result indicated that the locomotive cannot be manufactured with present technology if the 80 tonne weight limit is to be met.

5. BBC-Switzerland has an order from the Swiss Federal Railway for 10 Ee 6/6 four quadrant converter electric locomotives (1.0 MW). The first of these are to be delivered next year.

The delegation members visited the marshalling yard at Limmattel where three of the AM 6/6 locomotives are in humping service. We rode and inspected the locomotives.

1.2 Visit to BBC - Manheim, Germany

The purpose of the meeting with BBC-Germany was to discuss advanced propulsion systems with special emphasis on the four quadrant converter - AC drive, high power (5.6 MW) E120 electric locomotive and the DE 2500 diesel-electric locomotive with AC drive transmission. The principal points brought out in the discussion were:

1. Five E120 locomotives were ordered by the German Federal Railway (DB). The first one is to be available for exposition in June, 1979. The thyristors will be oil-cooled. The locomotive propulsion system will consist of four quadrant converter on the line side designed for unity power factor operation and extremely low harmonic generation and four PWM inverters with three phase AC asynchronous (induction) motors on the motor side.

2. Six E1200, dual frequency (16 2/3-50 hz) electric AC drive locomotives are now in service on the RAG in the Ruhrkohle industrial area. These locomotives are 1.5 MW each and have been praised by the customer on their superior performance. The thyristors are air-cooled. The propulsion system has a phase controlled rectifier on the line side rather than a four quadrant converter, since there was no need for power factor or harmonic interference improvement.

3. In 1971, one DE2500 prototype diesel-electric locomotive (six-axle) with AC drive transmission (1840 kW) was put on disposal to the DB. In 1973, two more DE2500 prototype diesel-electric locomotives (1-four axle, 1-six axle) were also manufactured. One of these locomotives has been run to a top speed of 98 MPH (158 km/h).

The AC drive consists of a PWM inverter with three phase AC induction motors. Initially induction motors with very compact winding ends were used. These winding ends overheated and led to failures in some cases. Subsequently, the winding ends were altered to provide better cooling and there have been no failures since that modifidation.

4. In mid-1974, one DE2500 prototype locomotive with diesel engine, alternator and rectifier disconnected was coupled to a power car which was a coach containing pantograph, transformer and prototype four quadrant converter. This combined unit served to prove the system envisaged for the future locomotive E120.

5. Other electric and diesel electric advanced propulsion units were produced by BBC-Germany. BBC-Germany has the most practical experience in advanced propulsion development.

Several other technical points concerning advanced propulsion system development by BBC are contained within this report.

Two survey trips were taken to inspect and observe the advanced propulsion developments.

1. The DE2500 (six axle) (blue) diesel-electric, AC drive locomotive was inspected and ridden by the delegation at the head of a 1430 ton (1300 tonne) freight train from the DB engine house in Mannheim to Heilbron, approximately a two hour trip. The route followed the Neckar River along a climbing grade. Performance was excellent.

2. The E1200 was inspected in freight operation at Essen in the Ruhrkohle area. The delegation rode the locomotive which was hauling a trailing load of 1667 tons (1512 tonnes). During this trip the train was halted and wheel slip control was demonstrated.

The area over which freight is hauled contains power generation and coking facilities. Commutator flashovers are a constant problem and the AC drive eliminates this problem. Performance of the E1200 is excellent and the RAG is well satisfied with the AC drive locomotives.

1.3 Visit to AEG-Telefunken - Berlin, Germany

The purpose of the meeting with AEG was to discuss their progress in AC drive technology and their progress in applying Sector Control to AC traction systems. Two members of the delegation (J.W. Marchetti and R.A. Uher) were present at these discussions. Principal points of interest were:

1. AEG has taken a different approach to the AC drive system. They are using a Phase Sequence Inverter (PSI) with low inductance, three phase AC asynchronous motors. This inverter is variable frequency and requires a variable voltage supply. The principal advantages of the PSI system are lower cost, use of slow rather than fast turnoff thyristors and less complicated electronic control. A prototype (1.5MW) laboratory version of this system is now being tested. No revenue motive power has yet been built by AEG using this inverter. AEG has produced a PWM AC drive for one married pair of cars for the Berlin Subway. These cars are in revenue operation.

2. AEG has developed sector control on the line side of the propulsion system for power factor improvement and harmonic reduction. Sector control uses forced commutated devices in the phase controlled bridge which can be turned off once per cycle. It is less complex than four quadrant control, however, it cannot achieve unity power factor nor can it reduce line harmonics to the extent of the four quadrant converter. Power factor is normally 0.9 with sector control. Prototype sector control propulsion has been placed on two series 181.2 locomotives (out of25) and on 3 E420 trainsets. Both types of motive power use DC traction motors.

3. The DB has already selected the four quadrant control - PWM AC drive locomotive as its future direction. Therefore, the PSI-AC drive will be developed by AEG for export rather than for the DB.

A tour of the AEG-Telefunken Traction Works in Berlin was undertaken. The PSI system (1.5MW) including a pulsed rectifier on the line side and which was on test was demonstrated.

1.4 Visit to Siemens AG - Erlangen, Germany

The purpose of the meeting was to discuss the progress of AC drive development with Siemens and to obtain their philosophy on advanced propulsion systems in general. Two members of the delegation (J.W. Marchetti and R.A. Uher) visited Siemens and the principal observations were:

1. Siemens, like AEG, has selected the Phase Sequence Inverter as their approach to AC drive equipment. They have produced PSI-AC drives for rapid transit vehicles:

1 Prototype car for the Vienna Subway

8 Prototype cars for the Nurnberg U-Bahn.

Both propulsion systems operate from 600-750 VDC and require choppers on the line side of the PSI to vary the voltage. They have already completed testing of a laboratory model of a PSI with a pulsed rectifier on the line side for achieving near unity power factor and for harmonic reduction.

2. Siemens responded to the information request sent before the visit. Using a Metroliner type tractive effort-speed curve as the basis, they analyzed three advanced propulsion systems as alternatives to future Northeast Corridor Motive Power. These were a modified ET403 propulsion (phase controlled rectifier with DC traction motors), sector control with DC traction motors and sector control with a PSI with three phase AC induction motors. Addition of a pulsed rectifier rather than sector control with the PSI which would achieve unity power factor and substantial harmonic reduction was considered as an afterthought. Their recommendation, without knowing details of NEC operation, would be sector control with PSI and AC induction motors.

A tour of the Siemens facility included:

1. Observation of the Magnetic Levitation Test Track, a joint project by AEG,BBC and Siemens.
2. Observation of their Monorail Test Track.

3. Observation and inspection of their battery powered, chopper controlled electric vehicles.

The Magnetic Levitation and Monorail test tracks were not in operation. However, we were able to drive one electric vehicle whose performance was excellent. It is used in the Siemens facility to transport and deliver mail.

1.5 General Observations and Conclusions

During the visits to the German electrical manufacturers, we picked up a general philosophy and some conclusions which were shared by all.

1. The DB is going to AC drive equipment because it is seeking a universal electric locomotive, namely: one that can be used in both passenger and freight service without a gear change but yet with enough power and electrical rating capability in the motors so that they can fit on the axles. After a competition among the electrical manufactures, the DB selected the Brown Boveri PWM AC drive for the five prototype, four quadrant controller, AC drive, E120 locomotives. For diesel-electric locomotives to replace the diesel-hydraulic fleet in the future, again AC drives were selected over DC drives.

2. In terms of practical experience with AC drive equipment, BBC is ahead technically. They have produced 37 units of one sort or another (diesel, electric) subway equipment. The other companies are less advanced in this technology.

AEG-Telefunken is the technical leader in the field of sector control, having applied it to a number of electric locomotives (DB E181.2) and (SAR 7E)* and self-propelled commuter cars (DB ET420, ÖBB4020).

Siemens has the most experience with the PSI as applied to AC motors. It has produced nine units for various subway equipment and has completed testing on a laboratory unit.

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* In cooperation with other electrical companies.

3. At the present time, AC drive technology has reached the point where PWM inverters up to 1.5 MW can be produced in production quantities (no longer prototype) for use in Germany and Switzerland. Units of higher power used in locomotives of 5 MW are still in the prototype stage and are probably five years away from production quantities. However, because of the different conditions experienced on the NEC, 1.5 MW units should be considered as prototypes until they are tested here.

4. Advantages/disadvantages of AC drives as compared to more conventional equipment (phase controlled rectifier DC traction motors) are:

a. The AC drive may be advantageous in that it removes the commutator from the DC motor and replaces it with an on-board solid state commutator which is more reliable (not subject to wear and flashovers) thus reducing overall maintenance cost. This is a subject which has been debated from time to time recently. There is evidence both pro and con to this argument.

b. The first cost of the AC drive is higher than the DC drive. At present this fact is certainly true. However, an argument in favor of lower cost AC drives for the future is stated on the basis that (1) the AC motor is less expensive than the DC motor and (2) the cost of the inverter, which is typically 1/3 thyristor cost will be reduced in the future. Thus the cost of AC vs DC drive is expected to come closer together in future years.

c. Bogie weight for same power or same tractive effort favors the AC drive. This probably a true statement although the monetary value of low bogie weight on motive power can't be quantified. There are methods of reducing bogie weight by using body mounted motors.

d. Energy consumption of DC vs AC drives is about the same while doing the same job. A DC motor has twice as many losses as the AC motor; however, the inverter probably makes up these losses so that both systems are nearly the same. On the line side, equipment used to correct power factor such as the four quadrant controller or pulsed rectifier can provide an overall increase in efficiency from power plant to substation to line to locomotive.

e. Automatic slip control of AC motors occurs because torque automatically falls to zero when slip frequency goes to zero. This allow operation at limits of adhesion. On an individual axle basis and for motors operating from the same inverter, automatic slip control is guaranteed. However, if all motors powered inverter slip, some means must be provided to detect and correct the condition. Thus, the question to be answered is whether the AC drive can do better in terms of working near the adhesion limit than modern DC drives with individual axle slip detection and correction.

f. Higher voltage motors can be used for AC drives thus reducing overall current carrying requirements of cables. However, insulation requirements of equipment must be raised.

g. The risk factor (something new) favors the old DC drive.

5. In terms of the line side of the propulsion system for future NEC equipment, the requirements are still unknown. Much will depend on the system voltage and frequency finally selected. If poor power factor and high harmonic content can be tolerated, phase controlled rectifiers are the least expensive and most reliable. If, on the other hand, high power factor and low harmonic generation is the requirement, something more sophisticated, such as sector control or even four quadrant control or pulsed rectifiers may be required at progressively higher cost. Again, the more sophisticated the requirement, the more complex the equipment and the less reliable.

Because of the pros and cons developed, it will be necessary to run extensive tests on U. S. railroads before answers to these questions can finally be determined.

2.0 DETAILED REPORT OF BBC - SWITZERLAND MEETINGS

On June 12-13, 1978, the delegation visited the BBC Oerlikon Works, in Oerlikon, a suburb of Zurich, Switzerland. Principal participants representing BBC-Switzerland were:

Dr. Zarko Filipovic, Chief, Export Business
Mr. Bruno C. Brom, Chief, Export 50 Hz - Alternating current traction powered vehicles
Mr. M. Roffler, Electrical Engineer, Export 50 Hz

Activities during the two day visit were:

June 12 AM - Technical discussion
PM - Shop tour, BBC Oerlikon-Locomotives
PM - Observation of Am 6/6 Diesel-electric locomotive in humping service at Limmattel yards
June 13 AM - Shop tour-electrical equipment; Technical discussions

2.1 Facts Concerning BBC

BBC does an annual business of $4.5B dollars (9B Swiss francs) and employs 100,000 people. The BBC group consists of a French, German and Swiss company and does 1/3 of its business in export and 2/3 in domestic. The Swiss company is located at Baden and Oerlikon and does 80% export and 20% domestic business. The electric portion of the traction business is at Oerlikon and 58% of this is DC equipment and 42% is AC equipment, which includes diesel-electric.

The DC equipment is built for rapid transit and trams and consists of resistor notching (cam-type control) and choppers.

The AC equipment for mainline and shunt rail service consists of multiple unit cars, electric locomotives and diesel electric locomotives. Among the AC equipment produced are:

1. Conventional tap-changer, single phase AC (16 2/3 Hz) electric locomotives.
2. Line commutated-thyristor controlled motive power (phase control).

3. Diesel-electric locomotives with inverter controlled three phase AC induction motors.

2.2 The Am 6/6 Diesel-electric Locomotive

Most of the material describing the locomotive operation is contained in the BBC review article (No. 12-1977) Attachment A and will not be repeated here. Just highlights and new material are presented.

The first BBC (Switzerland) work with AC drives began in 1967 with a power car of the DE 4/4 series converted to AC drive and renamed the BE 4/4. This car began operation on 15kV, 16 2/3 hZ in 1972.

In December, 1973, the Swiss Federal Railway placed an order for 6 Am 6/6 diesel-electric, AC drive locomotives. The specification included the requirement that on a 2.5% grade the locomotive be capable of accelerating a 771 ton (700 tonne) train to 12 MPH (20 km/hr).

The propulsion system consists of engine running a three phase alternator whose output is rectified. This output is fed to a PWM inverter in parallel with a capacitor. The output from the inverter is used to control the traction motors, which are three phase AC induction type.

A constant voltage is maintained at the capacitor so that the inverter provides variable frequency, variable voltage output to the motors. Control of the voltage at the capacitor is maintained by varying alternator excitation.

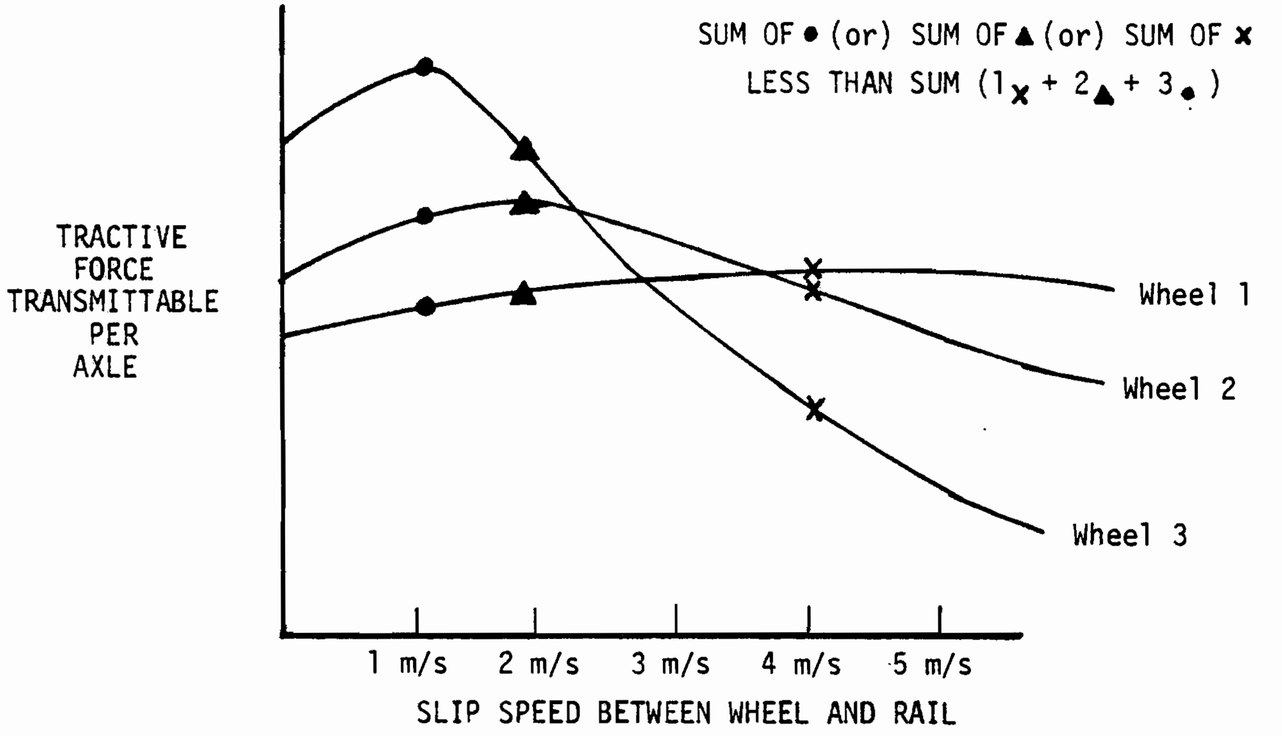
The circuit contains a three phase smoothing reactor which has magnetic coupling circuits which balance the phases.

The inverter is liquid cooled (oil) by being submerged in a tank. This is good maintenance-wise because no cleaning is required. However, should there be a failure the whole unit must be removed. BBC claims a large improvement in reliability by going to oil cooling so that with the addition of redundancy, maintenance need only be performed when the locomotive is in the shop.

Fault protection is achieved by turning on all thyristors in the inverter and opening the contactor to the alternator. In this way, the fault current is shared by all thyristors rather than one, which would be damaged.

2.3 Adhesion and AC Drives

When connecting asynchronous motor driven axles in parallel to the same inverter, the axles cannot individually slip. As the adhesion characteristics of each axle vary considerably due to the rail conditions as shown in the figure below, the highest possible tractive effort cannot be transmitted to the rail as all axles are not running on the same adhesion characteristic.



Experience shows that under bad rail conditions the adhesion maxima can differ by up to 3 m/s. Because of the rigid speed coupling of parallel connected asynchronous motors, wheel diameter differences of up to 2 mm are allowed in a single bogie. In different bogies, wheel diameters of up to 20 mm are allowed. As opposed to conventional diesel-electric locomotives power does not have to be reduced when the anti-slip device functions. When the speed difference between both bogies is too high, the torque is quickly and momentarily reduced. Since this torque reduction lasts for approximately 50 ms, it is not noticable in the tractive effort or diesel engine speed. An additional measure for improving the adhesion conditions (cleaning the treads on the wheels) is applied by means of a "slip brake." Because of this method for correcting slip which is matched to the three phase drive technology, best possible adhesion is obtained under worst rail conditions.

2.4 Capital Cost Information

We were given the cost ratios when comparing a four quadrant controller locomotive to a thyristor phase control locomotive. At 5MW and 1.2MW the electrical equipment is 60% of total cost and mechanical equipment is 40%. The above figures are based on 40 locomotives. On the basis of higher numbers of locomotives (~500), these cost figures would come down because on such a large order, special thyristors could be designed.

2.5 Reliability Related Item

The phase controlled rectifier locomotive has approximately 350 electronic control components while the four quadrant control-AC drive locomotive (re 4/4 UR) has 4000-5000.

The six locomotives produced are having some problems. About 30 thyristors have been lost thus far. The locomotives went into service in May, 1977, and through June, 1978, accumulated 6835 mi (11,000 km) of operation per locomotive.

2.6 Future Plans

BBC has an order for a series of 10 Ee 6/6 electric locomotives with four quadrant control on the line side of the propulsion system and PWM AC drives on the motor side. They are very low power locomotives (1MW) requiring one inverter for six driven axles. The first of these are to be delivered next year.

BBC (Switzerland) said that they would not yet take a large production order for 5MW mainline four quadrant converter locomotives at this time because of the weight, volume and the large number of components (reliability). At least five years are required.

2.7 Comments on Touring Part of Trip

The first part of the tour was spent looking at the Re 6/6, tap changer electric locomotives. This basic locomotive is described in a BBC review article (12-1977).

The Am 6/6 locomotive with three phase AC traction (diesel-electric), which we rode was in humping and shunting service in a yard near Oerlikon. It had 11,000 km (6835 mi) of service logged on its speedometer. Three of the six locomotives are being used for humping service in these yards. Maximum tractive effort at any point on the speed/tractive effort curve can be held continuously even at standstill.

The electrical works at the Birr shops which manufacture rotating electrical machinery with ratings to 2,400 MVA, as well as locomotive traction motors were also imspected. A TVA turbine powered generator set with an output of 1,400 MW was under contruction. The Birr shops occupy over 5.7 million square feet of floor area and employ 2,250 people.

3.0 DETAILED REPORT OF BBC-GERMANY MEETINGS

On June 14-15, 1978, the delegation consisted of:

J. A. Bachman - Unified Industries, Inc.
J. W. Marchetti - J. W. Marchetti, Inc.
R. A. Uher - Carnegie-Mellon Univeristy

The principal participants representing BBC-Germany were:

Mr. Eric Kocher, General Manager, Traction Division
Mr. Heinrich Kafer, Manager, Professional Staff, Traction Subdivision
Mr. Werner Teich, Manager, Diesel and Industrial Locomotive Department
Mr. Albrecht Graefen, Diesel and Industrial Locomotive Department
Mr. Joachim Korber, Manager, Electric Locomotive Department
Mr. Ernst Becker, Electric Locomotive Department
Dr. Rudolf Winden, Manager, Electric Multiple Unit Department

The schedule of activities during this visit with BBC-Germany was:

June 14 AM - Technical Discussions
PM - Observation of DE2500 in Freight Service
June 15 AM - Technical Discussion
PM - Observation of E1200 locomotives of the RAG

An organization chart of BBC-Germany Traction Division is provided as Attachment C.

3.1 History and Future Development of Advanced Propulsion by BBC

Table 1 illustrates the developments of advanced propulsion systems by BBC (Switzerland and Germany).

Three phase AC traction was developed by BBC for certain advantages:

1. Light trucks because of smaller weight AC induction motors.
2. Electric compensation for axle load variation.
3. High power factor and low harmonics on the line (four quadrant control).

BBC indicates that AC drives for light traction (trams and subway cars) are not as beneficial as for heavy traction.

TABLE 1

HISTORICAL DEVELOPMENT OF AC DRIVE

(Brown Boveri)

Date	Item	Remarks
1971	1 - DE2500	A diesel-electric locomotive of 2500 hp with an AC drive transmission. Three locomotives were ordered by DB.
1972	BE 4/4 (Swiss)	This was an electric rail car of type DE 4/4 which was modified into an AC drive for experimental purposes.
1973	2 - DE2500	The two remaining diesel-electric locomotives were put into service.
1974	EET	This was a 5 MW inverter which was developed for a linear motor.
1974	DVF - Prototype	This unit consisted of a power coach coupled to a DE2500 locomotive. The power coach held a transformer and a four quadrant converter. This was the test vehicle with a prototype four quadrant converter. The AC drive of the diesel-electric locomotive was used as the driver.
1975	1600P	This unit is a 1.5 MW inverter coupled to one AC Traction Motor and put on a on a converted DE 2500 for testing. This system operates from 1500 VDC and can be considered a prototype for the AC drive of the E120.
1976	6-Am 6/6 (Swiss)	Diesel-electric locomotives with AC drives for humping duty and thermal operation reserve on the Gotthard line. (A line having large and long grades).
1976	6 - E1200	Dual frequency (16 2/3, 50 Hz) electric AC drive locomotives for RAG for coal hauling service in the Ruhrkohle lands. Each locomotive output is 1500 kW. The line side uses a controlled rectifier (not four quadrant control).
1977	6 - EDE 1000/500	Dual frequency (16 2/3, 50 Hz) and dual propulsion (diesel-electric/electric) locomotives. These were built and put into service in 15 months
1979	5 - E120	Electric locomotives for both passenger and freight service rated at 4400 kW with a 20 minute rating of 5600 kW.

The table below describes thyristor development history in terms of power and quantity required for traction application as seen by BBC.

YEAR	NO. OF THYRISTORS/MW	
1966	300	
1971	80	(DE2500)
1973	60-70	(2-DE2500)
1978	40	(E120)

3.2 The DE2500 Diesel-Electric Locomotive

This diesel-electric locomotive has an AC drive transmission consisting of a PWM inverter with three phase AC induction motors. A description of the locomotive appears in Attachment D and is not repeated here. Items which are not contained in that report but were conveyed to us by BBC are:

1. The locomotive has been run up to a top speed of 158 km/hr.

2. In the initial stages, induction motors with compact end windings were used. Some of these failed and it was found that it was necessary to alter the winding ends for better cooling. After the winding ends were altered, there were no motor failures.

3. Maximum switching time for the thyristors corresponds to a frequency of 200 Hz.

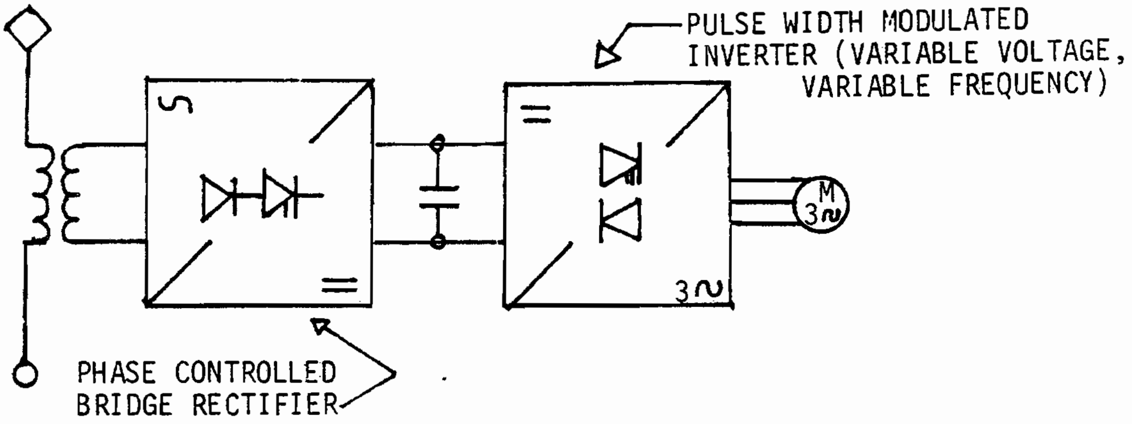
4. The diesel-electric locomotive alternator can be designed and sized to the output of the diesel engine because the inverter can match the power output of the diesel engine. In the case of diesel-electrics with DC drives the alternator must be sized 40% more than the diesel engine in order to accommodate starting currents.

3.3 The E1200 Electric Locomotives of the RAG

3.3.1 Locomotive Description

A description of the E1200 electric locomotive used for coal hauling service in the Ruhrkohle area appears in Attachment E. Other facts not mentioned in this attachment but learned in both the discussions and on the inspection trip are listed here.

1. The six E1200 locomotives are dual frequency (16 2/3-50 hz) at 15 kV. They do not have four quadrant converters but rather the system described schematically below.



The controlled rectifier is used to maintain a constant voltage on the capacitor independent of the line voltage (i.e., to correct for line voltage variation).

Cost information on the E1200 follows: Siemens and AEG-Telefunken bid $600 k ($1.2M DM) each for the E1200 and proposed phase controlled locomotives. BBC (German Group) bid $500 k ($1.0M DM) each for the inverter AC motor locomotives. These prices apply to electrical equipment only.

It seems that the reason for the low price for the AC drive locomotive may not be due exclusively to low cost but involve other factors.

The E1200 has less than 2.3% current ripple in the traction motors. It does not have regeneration capability but does have dynamic braking. It also has the capability to use one of the traction motor inverters as an auxiliary inverter, should the auxiliary inverter fail.

3.3.2 Experience with E1200 locomotives at Essen

On the afternoon of June 15, 1978, we visited the Ruhrkohle AG (RAG) railroad at Gladbeck near Studtgartd. Ruhrkohle AG consists of three companies which run the mines. The railroad transports coal between the 12 pits and ten power stations. Statistics on the railroad which is privately owned (not part of DB) are as follows: (a book was provided)

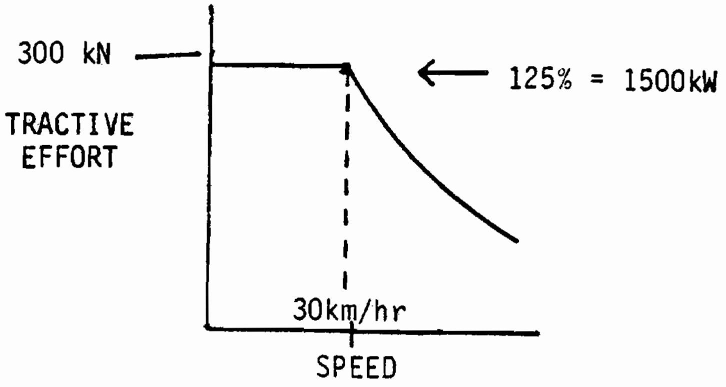
1. Tons of coal/year = 67.5 million
2. Tons of coke/year = 22.5 million
3. There are 250 mi (420 km) of track

Observations from the ride we took on the E1200 locomotive on a real service run:

1. Locomotive weight was 97 tons (88 tonnes) and the net weight of the train was 1667 tons (1512 tonnes).

2. The auxiliary inverter runs at a different frequency at standstill since the DC link capacitor voltage is only 1200 volts (rather than 1500 volts) thus, the frequency at standstill is 40 Hz rather than 50 Hz. Once power is drawn, the capacitor voltage goes up to 1500 volts and the auxiliaries run at 50 Hz. This effect is noticeable.

3. The locomotives were originally designed for 100% of full power. In service on normal days, RAG with BBC concurrence found that they could run at 125% full power without problems. This is now normal operation. On hot days, it is necessary to cut back to 100% full power, the original design point. Note that any point on the tractive effort-speed curve can be held continuously. See illustration below.



4. A slip control demonstration was held for us to observe. The rail was oiled on both sides of the locomotive ahead of the front axle. Initially, they were not able to make the demonstration work because (they said) the rails in the area were too slippery. As a result, all axles were slipping and the overall slip control, which reduces power to all axles, went into action.

Power is reduced immediately and full power is restored to all axles. Finally, after moving the locomotive forward somewhat, and pouring sand under the three back axles, they were able to make the demonstration work. A dynamometer car behind the locomotive was observed during the test.

a. Full tractive effort with all four axles not slipping 67.4k lbs. (300 kN)

b. Full tractive effort with one axle slipping and remainder holding was nearly 22.5 k lbs. (100 kN) for each of the non-slipping axles.

5. There is heavy coal tar residue and smoke since the whole area is heavily industrialized and commutator flashovers are a constant problem with DC traction motors. This was one reason why the three phase AC drive was selected.

Further discussions and facts concerning the E1200 cost, performance and reliability and maintainability:

1. There are thirty-two electric locomotives in the RAG fleet. Six of

these have three phase AC drives and 26 are phase control with DC motors. All are equipped with thyristors.

2. Delivery of the AC locomotives occurred over the period September-November 1976. At the present time, the six locomotives have accumulated 72-99,000 mi (120-160,000 km) with the highest value being 35,400 mi (57,000 km) and the lowest 16,800 (27,000 km). The locomotive that we rode had 21,800 mi (35,065) of service.

3. Reliability and maintenance cost data were freely given on a comparison basis. Table 2 compares the performance of a sample of diesel-hydraulic, phase-control with DC traction and inverter control with AC traction.

Remarks on Table 2 are as follows:

1. It was not clear what was meant by life cycle cost. We think it included the investment as well as maintenance and other operating costs.

2. In the phase-control DC traction case, $4-10k ($8-10k DM)/year must be included for batteries and battery maintenance.

3. The portion of the above maintenance cost which is mechanical rather than electrical was not known at the time of the visit. (This information will be sent to us later.)

4. Maintenance history of phase control locomotives in constant $(DM) was not available. (This information will also be sent to us.)

5. The phase-control DC traction locomotives have about 12 years of service on the average or 240,000 mi (400,000 km) of use. However, the inverter-three phase drive AC locomotives have 1.5 years of 21,700 mi (35,000 km) of use on them.

6. The Ruhrkohle routes are laden with coal dust, power plant and coking plant pollution and provide a bad environment for DC traction and contactors. Thus in this special application this fact alone could favor AC drive.

TABLE 2

ADVANCED PROPULSION
MAINTENANCE COST COMPARISON (RAG)

	Diesel-Hydraulic	Phase Control DC Motors	Inverter Control AC Motors
Number of Locomotives in Sample	4	16	6
Age (years)	12-14	9-14	1.5
Service Level $\left(\frac{\text{Million Ton-Miles}}{\text{Year}}\right)$	6.87	13.75	20.62
Maintenance Cost Index			
1. $/Year/Locomotive	91,250	43,550	24,550
2. $/Ton-Mile	.0133	.00316	.00119
Life Cycle Cost ($/Locomotive/Ton-Mile)	.0399	.0209	.0183

Other information and answers to questions on reliability are as follows:

1. Wheel changes and maintenance - On the phase-control locomotives, the wheels are machined every 2-3 years. The time on the inverter locomotives is too short for any data on wheel maintenance for comparison.

2. Inverter failures - Of the 30 inverters supplied to the locomotives, there are 20 inverter failures in the first six months of the experimental test period. The problem was remedied and in the last six months of operation there were only 3 inverter failures. On the average over the past year, for all equipment, there are 2-3 faults per month per locomotive for the phase-control locomotives and 1 fault per month per locomotive for the inverter locomotives. On the inverter locomotives there have been no traction motor failures.

3.4 The E120 Locomotive and Four Quadrant Converter

The design of the E120 locomotive, which is a full four quadrant converter on the line side, and a PWM inverter on the motor side driving AC induction motors, is the first attempt at something in this power range (5.6MW).

A description of the propulsion system appears in Attachment B. Attachment F is a less technical version in English.

1. The thyristors are oil cooled but not in a tank as is the scheme with the Am 6/6 of Switzerland. Rather, oil is piped directly through the heat sinks of the thyristors and the remaining equipment is left exposed to the air. To avoid contamination problems, the Swiss went to all oil cooling accomplished by means of a tank. However, the German group does not follow this philosophy.

2. Philosophy developed on rectifiers for use with inverters driving three phase AC induction motors. The rectifiers can be

a. Diode rectifier

b. Controlled rectifier (used mainly for voltage regulation only)

c. Sector control, which is the same as a forced commutated controlled rectifier with one commutation per cycle of AC line voltage.

d. Four quadrant converter, which is the same as a pulsed rectifier (i.e., many pulses per cycle of the AC wave). The latter two rectifier methods (c. and d.) are used in order to obtain a high power factor and reduce line harmonics.

3. The first testing of a four quadrant converter was the DVF prototype discussed previously. The power factor was found to be >0.99 at full tractive effort. Further reduction of harmonics was achievable by using 2 four quadrant converters on separate parts of the transformer. They are pulsed opposite from each other in order to achieve cancellation. Use of four taps, six taps, etc., can further reduce harmonics, but the thyristor size and additional reduction limits this. More than four does not seem justified. (See for example, Fig. 3 of Attachment F.)

4. For a four quadrant converter, power factor is nearly always near unity, is not a function of speed but rather a function of power expressed as P/P max.

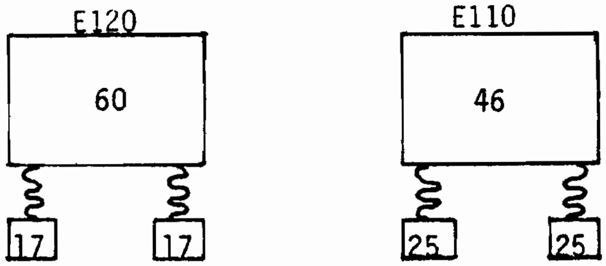
5. There is a weight savings on motors. For the E120, motor weight

3Ø AC Motors - 2.5 tons (2.3 tonnes) (1.4MW)

1Ø AC Commutator Motor - 4.3 tons (3.9 tonnes) (1.05MW)

Gear unit weights would be the same because both units would necessarily be single reduction.

6. A comparison of E120 weights and E110 weights (a locomotive of the same power with AC single phase AC motors) are shown below (in tons)



Total 94 96

7. The inverters are oil-cooled using pipes to the heat sink as previously mentioned. Weight savings by this method of cooling over that of air cooling is 2.2 tons (2 tonnes) for a 5600 kW inverter.

8. The thyristors used in the equipment are 1300 V and 750 amp devices. Tension is maintained on thyristors of torquing.

9. Readjustment of slip control electronics when changing bogies will not be necessary.

3.5 General Information on Advanced Propulsion

General information on advanced propulsion systems was presented. These topics are covered here:

3.5.1 Energy Efficiency

Losses in AC traction motors are roughly half those in DC traction motors. Thus, the efficiency of the AC drive is the same as the thyristor phase-control locomotive, even though the power is handled twice in the former case (once by the phase controller and once by the inverter).

3.5.2 Electronic Costs (Present and Future)

1. One present drawback of the inverter locomotives is the higher electronic volume both in power and control. BBC says that this is an advantage in cost, especially in the future.

2. One figure related to cost is that the ratio of (cost of electrical equipment) to the (total locomotive) is about slightly more than half.
This seems to agree with other information we've received from the other companies.

3. One cost factor brought out was that for the phase controlled rectifier electrical equipment 50% of the cost is in the power and control electronics and 50% is in the DC motors. In the case of AC induction motors, 20-25% of the electrical equipment is in the AC motors.

4. The cost of the electronic control for the E120 is quoted at 10-15% of the total electric work. The lower (higher) figure of 10% (15%) refers to control without (with) diagnostic equipment added.

A more thorough cost comparison of advanced to present propulsion systems is made in Section 4.

3.5.3 Inverters with DC Line Input

1. Either a step up or step down (voltage) chopper can be used when operating equipment from a DC line. The 1600P which is a one inverter-one motor prototype of the NS with components of the E120 operates from a 1500V line and steps up the voltage. Another application from either 600 or 750 VDC uses a step up chopper by chopping across an inductance to achieve the higher voltage.

3.5.4 Future Plans for Three Phase AC Drives

It is the DB intention to develop new equipment with AC drives, both locomotive-hauled, for intercity service. These include:

1. The E422, which is a trainset of 3 cars, two powered and one trailer. Power level will be 1700 kW and will be used on a 15 kV 16 2/3 hz. The weight of the electrical works would be 33 tons (30 tonnes) for 1600 kW. However, this is only a PWM inverter and motors. (This is only a study with little chance for realization by the DB.)

2. A new high speed train for intercity service. It is still in paper stage and will consist of 10 coaches with power cars at both ends. Total power levels will be 700 kW per motor, 2800 kW per power car or 5600 kW per train. It will be run in push-pull.

3.6 Diagnostics and Reliability Philosophy

The BBC uses a reliability and maintainability philosophy similar to what we teach in the United States but they put it into practice in their design. The basis for this seems to be that the DB will not tolerate unreliable systems on its railroad. A presentation on the considerations that went into the design of the electronic control package was made.

The principles that went into this design were:

1. Elimination of outside interference.
2. Modular design.
3. Separation of different voltage levels.
4. Analogue/digital separation.
5. Provision of interference zones on the cards. These provide protection.

There are two main concerns; namely, fail safety and reliability

1. Fail Safety - Generally have a double system for such functions with a comparison between these two systems. If the systems are not the same, they are shut down.

2. Reliability and diagnostics -

The learning process for building reliability into the equipment was a difficult one. It seems that BBC had many problems in their first attempts. The progression was as follows:

E320 - Diode locomotive
E410 - Phase control locomotive
E184.1 - Modified version of E410

The latest locomotive, which is the E120, will have 180,000 functions which will be provided using MSI and LSI. Although many more functions are required for this, the progress in reliability improvement of components over the ensuing years (from E320 locomotive to E120) has been such that the expected system reliability remained the same. They had a chart on which failure rate per function vs years and number of functions vs years was plotted to demonstrate that system reliability was remaining the same although functions were increasing.

As far as diagnostics are concerned, monitoring is accomplished on-board with diagnostic interface points built directly into the design. (A paper, in German, is written on this whole subject of reliability and diagnostics.)

3.7 Tour Portion

The IPEEP delegation was invited to observe the Co-Co DE2500 number 202004-8 (blue) locomotive in revenue service. The group boarded the locomotive cab at the DB engine house in Mannheim and rode in it to Heilbronn. The DE2500 hauled a freight load of 1430 tons (1300 tonnes) along a climbing grade route that followed the Neckar River.

A second visit was made to the town of Essen to observe the electric BBC E1200 industrial locomotive in service for Ruhrkohle AG. Ruhrkohle hauls about 66 million tons of coal and 22 million tons of coke annually over a 260 mi (420 km) company-owned network of tracks in the central Ruhr region of West Germany. The coal is hauled from mine to cokery and to power station.

The rolling stock manager for Ruhrkohle AG was very happy with the equipment and stated that maintenance hours have dropped significantly with the acquisition of the E1200 locomotives with PWM inverters and three phase AC induction motors.

4.0 DETAILED REPORT OF AEG - TELEFUNKEN MEETINGS

On June 16-17, J. W. Marchetti and R. A. Uher visited AEG-Telefunken in West Berlin and conferred with Karl Dreimann (EMU Project Manager, Traction Division) and W. Bronder (Director of Exports, Traction Division) on the subject. Activities during the two day visit included:

June 16	AM	- Technical Discussions
	PM	- Plant Tour including Laboratory Demonstration of a 1.5 MW Phase Sequence Inverter
June 17	AM	- Technical Discussions

Most of the day was spent with Karl Dreimann, who presented an excellent tutorial on the subject of both PWM and PS inverters with AC drives, and of a complete independent approach to the line side of the circuit between the transformer and the inverter. The line side of the DC link could take on various forms independently of whether the motor side consisted of DC motors or an inverter with AC motors.

4.1 General Discussion

General items of interest which were brought out at the meeting include:

1. The German Research and Technology Ministry (GTM) provides for the three electrical companies (Siemens, BBC and AEG) to cooperate in any research and development of new advanced equipment. This statement was of course verified by the other three companies. If on any development project, the GTM puts up 100% of the money, the GTM has the right to use the results for public (national or international) programs and orders and to sublicense to other companies on standard terms. If, on the other hand, the development is funded 50/50 government/industry, license would be given only to the German companies and not outside.

2. AEG sold phase-controlled DC-traction locomotives to:

NUMBER	CUSTOMER	TYPE	DELIVERY DATE
1	Rheinische Breunkohlenwerke	500	1962
24	Ruhrkohle AG	EA 1000	1965/66
4	DB (Two System Locomotives)	E181.1	1965
3	DB (Four System Locomotives)	E184	1966

3. The AEG approach to the AC 3Ø motor drive is different than the BBC approach. Where BBC is using a PWM inverter, which is essentially operating from a fixed voltage source, AEG uses an inverter which operates from an impressed current source and has variable frequency control only.

4. On the other side of the DC link, AEG is concentrating on sector control. Sector control is used only to "be friendly to the line" or the German word "netzfreundlich." This means that it is used (or rather circuitry is used) to correct line power factor and/or harmonics. At the present time sector control has been applied to:

1. Two locomotives (DB E181.2 series)
2. Nine cars or three DB ET420 trainsets
3. One Hundred Locomotives (SAR 7E)*
4. Forty EMU (OBB 4020)*

Both type units use DC traction motors.

5. In the next generation of equipment, the DB is expected to move directly to inverter control AC motors rather than the intermediate step of sector control. This has been their official announcement, and it is also the reason why the E120 locomotive prototypes are being developed.

4.2 Cost/Benefit Basis of Sector Control

Sector control when added to an already existing phase-control locomotive adds about 4-5% to the electrical cost which is about 60% of the locomotive cost. For new locomotives, about 3% would be added to the cost for sector control.

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* In cooperation with other electrical companies.

It takes the added equipment 5-13 years to pay for itself. The background of this cost/effectiveness estimate includes:

1. On the cost side:
   a. Equipment cost
   b. Additional maintenance cost
   c. Cost of money
2. On the benefit side:
   a. Reduction in line losses because of increased power factor
   b. Capability to run more locomotives on the line because of better voltage regulation again because of increased power factor.

Reduction in line losses was considered in the cost-benefit analysis. This was done using the following figures:

Ohmic losses in the substation transformer, catenary and vehicle transformer were taken into account because of the flow of reactive current. Efficiencies used were:

1. Catenary losses - 3.8% 2-line system
2. Catenary and Substation - 7%
3. Vehicle Transformer 2-2.5%

Thus a total of 9-9.5% are the total losses to contend with. It was found that for a particular mix of passenger and freight service on a particular German railroad line, the total average current is reduced by 20%, thus the losses are reduced by 34%. Thus the total power reduction is from: 34 x (0.09 to 0.095) = 3.1 to 3.2%.

However, one thing which was not taken into account in this calculation was the difference in efficiency between the sector control (self or forced-commutated phase control) and the regular phase control (line commutated). Because of the addition of the commutating circuit, the efficiency drops by about 0.5 - 1% and the phase control becomes 97-97.5% efficient rather than

98% as would be the case for line-commutation. This would reduce the energy savings figure from 3.1-3.2% to 2.1-2.7% and could make a slight difference in the cost-benefit analysis.

It should be stressed, that this analysis was done on a particular German railway using particular German conditions and could result in different conclusions under different conditions.

4.3 Advanced Propulsion Systems for Main Line-Single Phase AC

Advanced propulsion systems can be analyzed on both sides of the DC link, namely:

1. The line side
2. The motor side

These two analyses are independent and on the rectifier side, the analysis is directed to those precautions taken to reduce line harmonics and improve power factor, while on the other side, the analysis is whether to use a mechanical or electrical commutator.

Rectifier Types (line side)

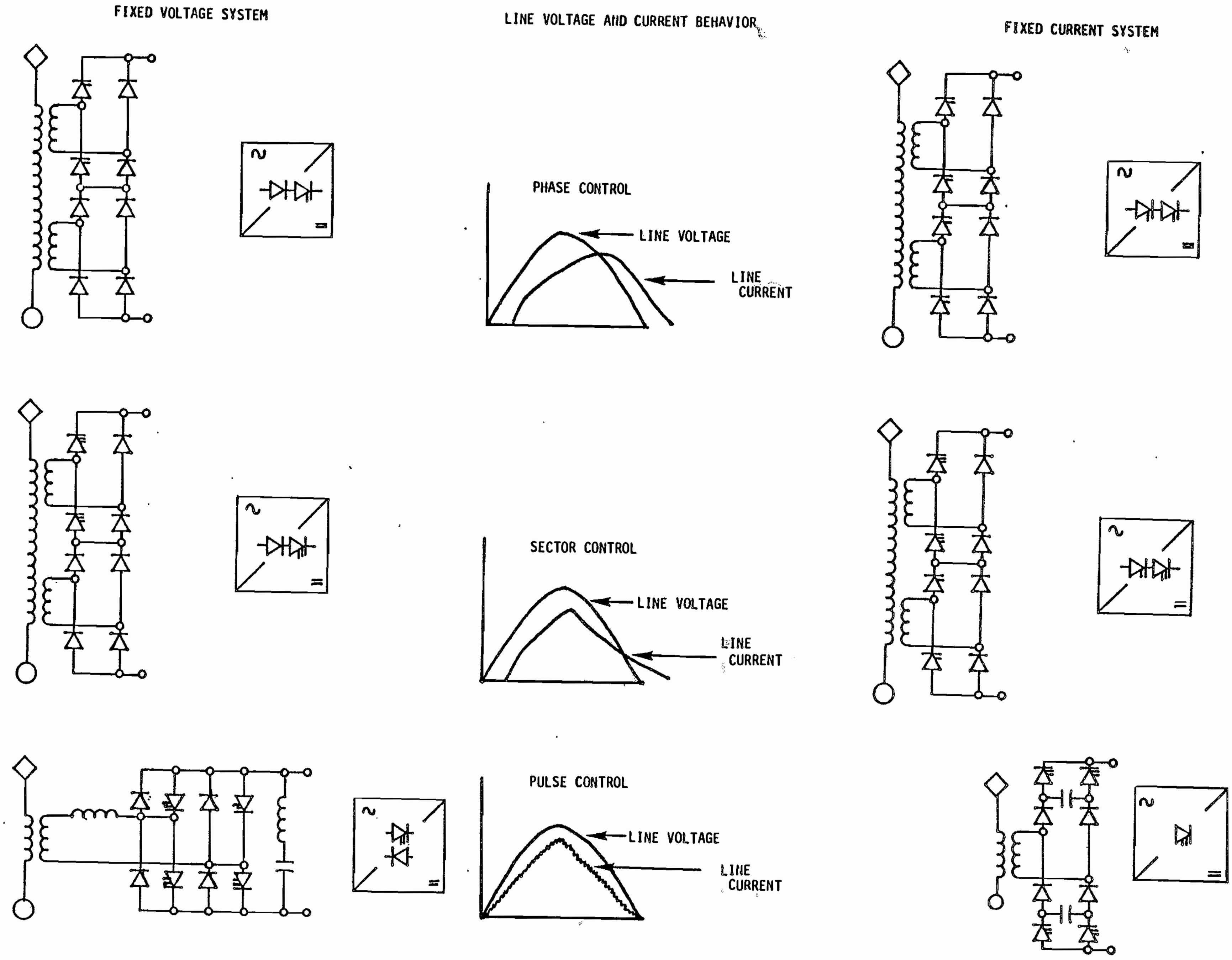
1. Normal Diode Rectifier
2. Phase Controlled Rectifier (Line Commutated)
3. Forced (Self) Commutated Rectifier (Sector Control)
4. Pulsed Rectifier

The three controlled rectifiers (2, 3, 4 above) are shown in Figure 1.

The diode rectifier has no voltage control capability, however, power factor generally near 0.9.

The line commutated, or phase control rectifier (PCR) has voltage control capability which is traded off for poorer power factor (0.1 - 0.9).

The sector control is a phase control rectifier with a commutating circuit. Power factor can be improved to (0.93 - 0.95).



RECTIFIERS WITH AND WITHOUT POWER FACTOR
AND HARMONIC CORRECTION

FIGURE 1

The pulsed rectifier (PR) of which the four quadrant controller is one kind, can improve the power factor to near unity (0.9999) and can reduce line harmonics quite substantially. It achieves this latter mission by pulsing on and off many times during a single cycle.

Inverter Types (machine side)

Two types of inverters are being considered by German railroad technologists. They are named:

1. Pulswechselrichter, which is generally translated as Pulse Width Modulated Inverter.

2. Phasenfolgewechselrichter, which can be translated as Phase Sequence Inverter or Interphase Commutated Inverter. The first type of inverter operates from a fixed voltage source, and has variable voltage,variable frequency control output, while the second operates from a current source, and only has variable frequency control output. BBC has chosen method 1 and Siemens and AEG Telefunken have chosen method 2. AEG has a 1.5 MW version of the method 2 inverter under laboratory test.

Figure 2 shows a comparison between the two basic inverters.

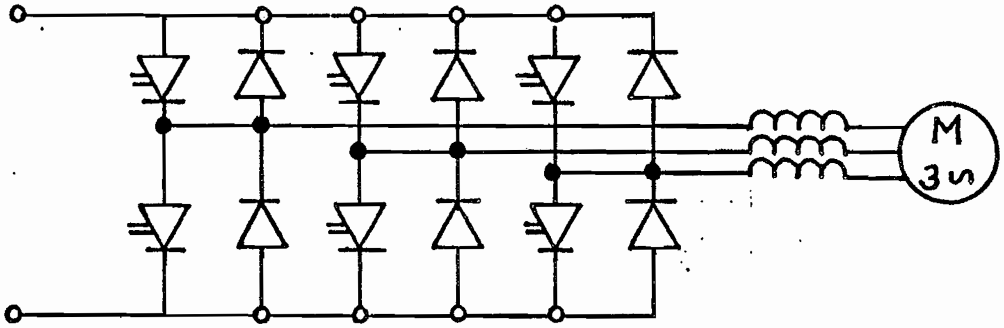
The phase sequence inverter is less costly and has less complicated control. It also requires low inductance AC motors to improve commutation.

The PWM inverter reverses current when in the regeneration mode while the PSI reverses voltage.

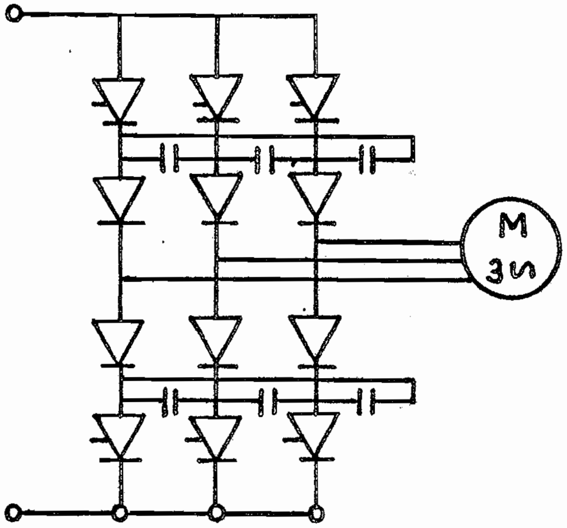
An estimate of capital cost breakdown is shown below:

AC Line Equipment (Locomotive) (Given by AEG Telefunken)
Estimated on basis of four axle, 5 MW locomotive

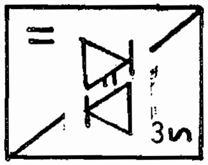
PULSE WIDTH MODULATED INVERTER

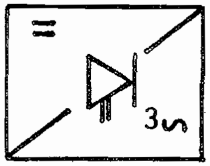


PHASE SEQUENCE INVERTER



CIRCUIT





SYMBOL

Variable Voltage
Variable Frequency
Requires Fast Devices
Has Constant Voltage Source

Variable Frequency
Requires Low Inductance Motor
Requires Slow Devices
Requires Variable Voltage Source

COMPARISON OF THREE PHASE AC DRIVE INVERTER CIRCUITS
FIGURE 2

Cost of Line Commutated Phase Control Rectifier Locomotive (in $)

1.	DC Traction Motors	$0.25-0.3 M
2.	Power Electronics	$0.15 M
3.	Control Electronics	$0.05 M
4.	Transformer, Pantograph & Remainder of Electrical Supply	$0.75-0.8 M
Total for Electrical Portion of Locomotive		$1.25 M

Cost of Four Quadrant Control, AC Inverter Drive Locomotive*

1.	AC Traction Motors	$0.125-0.15 M
2.	Power Electronics	$0.5-0.7 M
3.	Control Electronics	$0.1 M
4.	Transformer, Pantograph & Remainder of Electric Supply (Minus Reverser and Dynamic Brake Set Up Circuitry)	$0.7-0.75 M
Total for Electrical Portion of Locomotive		$1.425-1.7 M

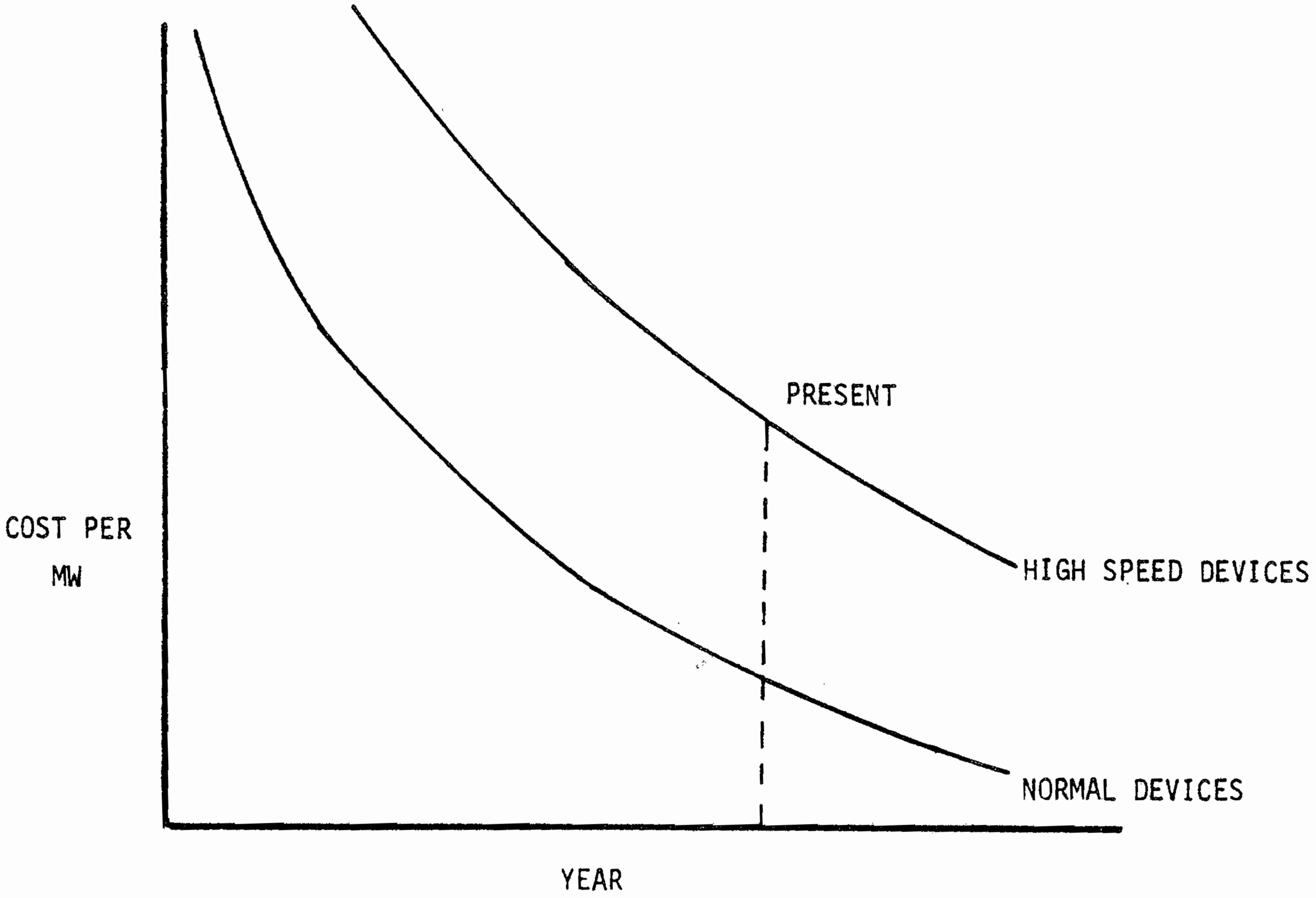
* Includes cost for regeneration equipment which is not in phase control locomotive.

The equipment for a forced-commutated phase control rectifier for power factor correction, adds 0.1 DM to the price of the line commutated phase controlled rectifier locomotive thus:

Comparison of Locomotive Types and Cost (in $M)

Type	Cost of Electrical Portion
Line Commutated Phase Controlled Rectifier	$1.25
Forced-Commutated Phase Controlled Rectifier	$1.3
Four Quadrant Converter - AC Inverter	$1.4-1.7

A word about reduction of cost for devices in the future. If we plot progress in thyristor cost reduction, it will look something like the figure below:



Improvement in thyristor cost will improve cost of PWM inverter system relative to IPC inverter system. However, the PWM will remain more expensive because of more semiconductors per unit, additional control electronics requirements and higher cost requirements of high speed thyristors.

Another cost breakdown given was:

1. Traction motors (AC) 10-15%
2. Power & control electronics 60-70%
3. The remainder of the electric works 15-30% (pantograph, transformer, etc.)

AEG feels that in five years the three phase AC drive will be a reality, especially on DB lines.

4.4 AEG Telefunken Advance Propulsion Experience

1. One prototype married pair of cars for the Berlin Subway (Series F76, No. 2578 2579) (PWM Inverter with three phase motors)
2. Sector Control on two locomotives, Series 181.2 (out of 25)
3. Three ET420 trainsets equipped with Sector control but DC motors
4. Sector control rectifiers for 40 EMUs of the Austrian Federal Railway
5. Sector control rectifiers for 100 locomotives of the South African Railway.

Descriptions of sector control and three phase drives appear in more detail in attachments.

4.5 Inspection of the 1.5 MW System in the Lab

The afternoon was spent visiting the AEG-Telefunken Traction Works in Berlin, to inspect the 1.5 MW inverter system. This was a phase sequence inverter. The demonstration was brief since the inverter was in the process of being tested.

The striking thing about the system was the large ironless reactor, which weighed 1430 lbs (650 kg) and was constructed of aluminum windings and iron. This large reactor is not required in a PWM inverter.

5.0 DETAILED REPORT OF SIEMENS - ERLANGEN MEETINGS

On June 21, 1978, J. W. Marchetti and R. A. Uher attended meetings with Siemens-Erlangen, Germany and conferred with Walter Lössel and Paul Rolf.

The morning was spent on technical discussions on advanced propulsion in the general conference room. The afternoon was spent touring the test facilities at Erlangen including:

1. The Maglev Test Track - Not in operation.
2. The Monorail Test Track - Not in operation.
3. We rode and drove the electric vehicles which were developed by Siemens and are used internally for mail delivery.
4. We also visited the lab where the 1.5 MW inverter - three phase AC drive system was set up and tested. The tests have been completed and the model has been dismantled.

5.1 General Technical Subjects

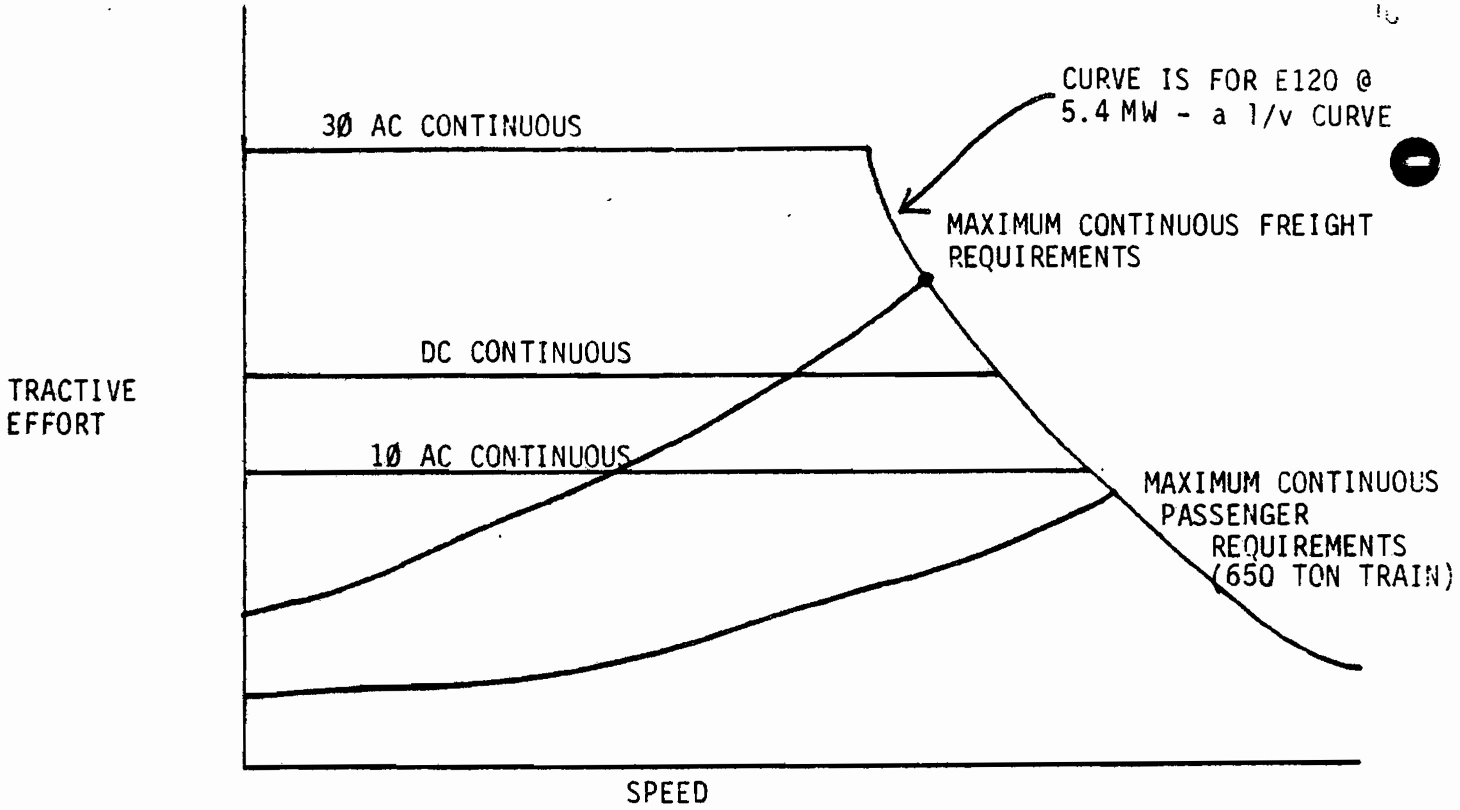
Siemens has produced phase control rectifier locomotives for the South African Railways. Their prototype three phase drive equipment include:

1. 1 car for the Vienna Subway.
2. 8 cars for the Nuremberg U-Bahn.

Attachment J&K describes these in greater detail.

Both systems operate from 600-750 VDC. These are all MU-car type operation. Siemens explained in great detail why the DB is proceeding directly from the old tap-changing single phase AC motor locomotive to three phase AC drive locomotives, the prototypes of which are the E120.

The three phase drive locomotive has a maximum tractive-effort speed curve such that every point within it can be held continuously. The figure shown below illustrates the point.



The DB wanted one locomotive to serve for both freight and passenger service. The present locomotives were not capable of doing this without a gear ratio change. However, since the AC drive locomotive can operate continuously at any point along the Tractive Effort/Speed curve, it can satisfy both requirements simultaneously. Above 120 mph (200 km/hr) a locomotive with a power capability of 5.4 MW would not be enough and their approach would be two power cars in push-pull configuration.

5.2 Recommendations for Advanced Propulsion for MU-Type Equipment for U. S. Operation

Siemens was the only one of the three companies which responded in earnest to the letter sent requesting information. They answered the questions, and using the Metroliner Tractive Effort/Speed curve as the basis generated a set of comparisons in document form on what three different types of propulsion equipment would do.

These three propulsion systems were:

1. Phase Control Rectifier (The ET403 Equipment) (DC motors)
2. Forced Commutated Rectifier (Sector control) (The ET403 equipment plus forced commutation circuits).

3. Sector control with a phase sequence inverter and 3ØAC motors.

In the three phase control frequency variation is accomplished in the inverter and voltage variation in the self-(forced) commutating rectifier.

Costs of the various systems were quoted as follows (electrical works only):

Item 2 - $425,000 car

Item 3 - $550,000 car

Item 3 plus a pulsed rectifier circuit - (Add $22,000) $572,000 DM 1 car.

Item 3 was suggested by them for operation in the NEC for 1981 and beyond. A comparison in weights is shown in Table 3.

5.3 Experience with Subway Type Equipment

1. On a 1200KW continuous vehicle, 1.125 ton/bogie is saved by replacing DC traction with AC traction.

2. In the case of the Nuremberg cars, one 6000KW motor drives two axles. There is a flexible coupling on both sides of the motor.

5.4 Maintenance and Reliability Considerations

1. Approximately 10% of the electrical equipment maintenance can be saved replacing DC traction with three phase AC traction.

2. After 1.8 M mi (3 M km) on the ET403, motor overhauls average 0.8 M mi (1.3 M km). It is estimated that AC motors can go 1.2-1.8 M mi (2-3 M km) between overhaul.

3. Siemens experience with solid state is limited. There are two prototype 1044 locomotives in operation on the Austrian Federal Railways. These are phase control rectifier, line commutated with DC traction motors. There are no problems with thyristors. (Ten of these locomotives are on order). One of the prototypes has over 0.6 M mi (1 M km) of running.

TABLE 3

COMPARISON OF EQUIPMENT WEIGHTS FOR METROLINER TYPE ADVANCED PROPULSION SYSTEMS

(All Weights in Lbs)

	Line Commutated	Self-Commutated	
	DC-Motors	DC-Motors	AC-Drive
Common Electrical Equipment *	3445	3445	3445
Main Transformer with Oil Cooler	3420	3640	3640
Auxiliary Rectifier	110	110	NR
Main Contactors (2)	77	77	NR
Line Contactors (2)	NR	71**	71**
Braking Contactors (2)	53	66	66
Smoothing Chokes (2)	1280	1320	1675
Rectifiers (2)	840	3350***	3350***
Phase Sequence Inverters (2) +	NR	NR	1520
Reversers (2)	49	49	NR
Traction Motors (4)	11375	11375	9260
Gear Units & Drives (4)	5510	5510	5510
Other Equipment ++	3970	4410	4520
TOTAL	30130	33420	33060

Notes:

NR	Not Required
*	Includes Pantograph, Main Circuit Breaker, Auxiliary Converter, Rectifier Cooling Fans Battery, Voltage Protection for Rectifier, Oil pump & Compressor and Braking Resistor.
**	Includes braking diode as well as contactor.
***	Includes Commutation Equipment (Capacitors plus extra thyristors)
+	Includes cooling equipment as well
++	Cable, wiring, mounting material plus miscellaneous equipment

5.5 Discussion on High Speed AC Motors

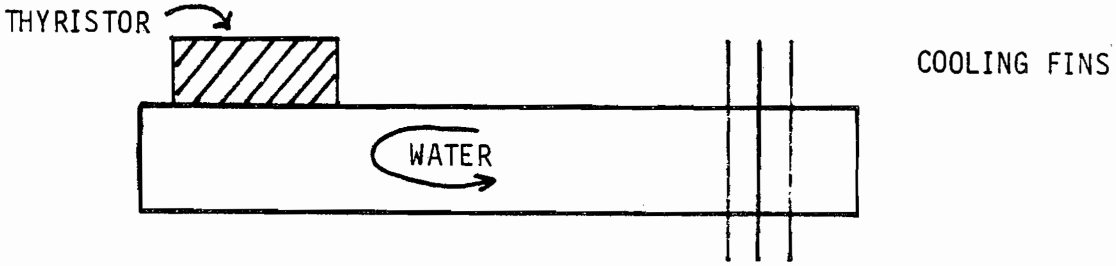
Of the three companies interviewed, Siemens was the only one optimistic about using high speed induction motors.

They claim that 4000 RPM intake limit for motors with greased bearings because centrifugal action causing the grease to stick to the outside. With pressurized oil lubrication, it is estimated that 8-9000 RPM may be achieved. Total overall weight saved would be something like 35-40% in motor plus gear unit. This weight savings includes equipment necessary for pressurized oil lubrication as well as additional weight required for gear unit to accommodate additional reduction of speed.

5.6 Items of Interest on Siemens AC Drive

1. Siemens had on laboratory test a 1.5 MW, pulsed rectifier, phase sequence inverter, three phase AC system. Tests have been completed and the equipment has been dismantled. The test set up was at Erlangen.

2. Oil cooled thyristors were used using piped oil directly to the heat sinks rather than tank immersion as in the case of BBC, Switzerland. An attempt is being made to do heat pipe cooling as sketched below.



The reactor is oil cooled.

3. The motor is a special type of induction motor with low inductance. This, of course, is required for the phase sequence inverter.

4. Thyristors can be divided into three general categories as shown below:

Category	Turn-off Time (Microseconds)	Voltage (Volts)
Slow	300	4000
Medium	100	2000
Fast	10-30	1400

In the Siemens system, medium turn-off time thyristors are used in both the rectifier and the inverter.

5. Voltage is controlled in the rectifier and frequency control is maintained in the inverter.

6.0 ADVANCED PROPULSION EXPERIENCE

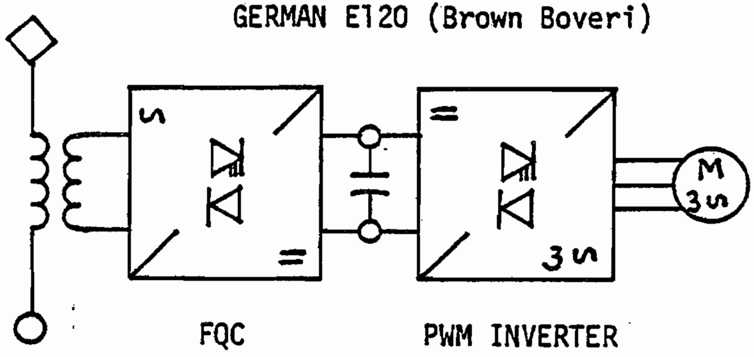
Figure 3 shows a comparison among several types of modern AC traction. First cost, maintenance cost, state of development and power distribution network effects are given a rank of 1 - 4 going from favorable to less favorable in the item compared.

The three phase drive units with good behavior on the power distribution network have the highest first cost but are expected to have the lowest maintenance cost because of elimination of the DC traction motors. The first cost of the four quadrant converter is expected to be more than the PR-PS Inverter unit because the former uses more fast turn-off thyristors in comparison and has more complex electronic control. In terms of state-of-the-art, the four quadrant converter prototype was tested on a DE2500 coupled to a power car on the road in 1974, while the PR-PS Inverter is only a laboratory model. In addition the PWM Inverter at 1500 KW is running under service conditions in six locomotives (E1200) for the Rag railway in Germany.

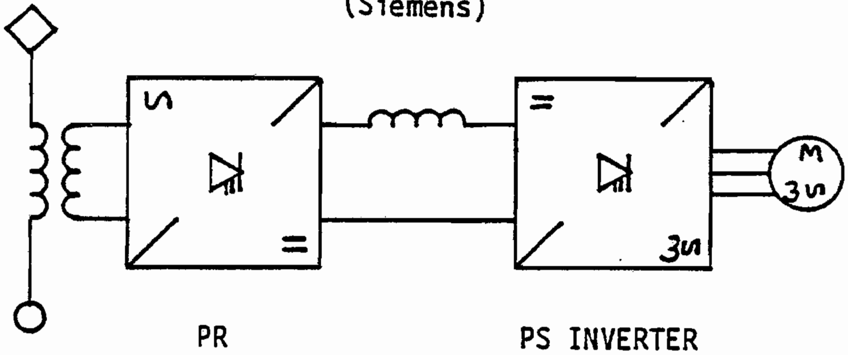
Sector control is expected to have the highest maintenance cost because of the extra complication in both power and control electronics while still retaining the DC traction motor.

Phase control is expected to have the lowest first cost and it is most developed with many examples of revenue operation.

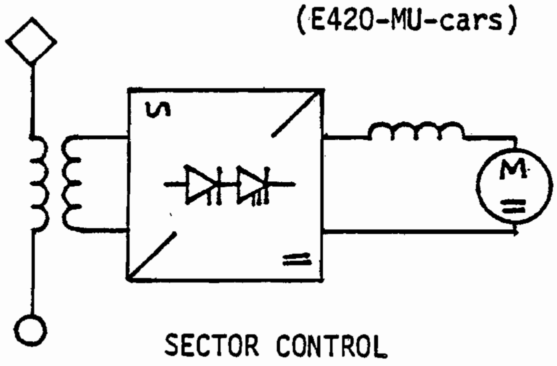
FOUR QUADRANT LOCOMOTIVE
GERMAN E120 (Brown Boveri)



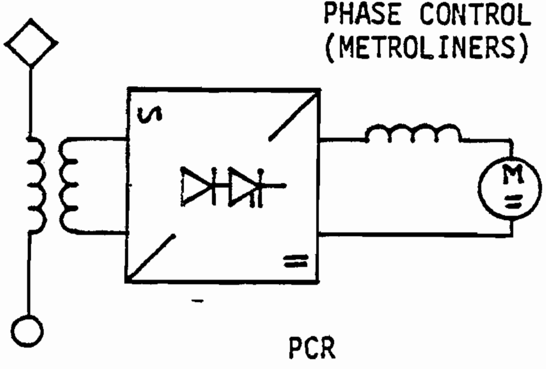
LABORATORY PROTOTYPE
(Siemens)



SECTOR CONTROL
(E420-MU-cars)



PHASE CONTROL
(METROLINERS)



FIRST COST	MAINTENANCE COST	STATE OF AR	POWER FACTO	LINE HARMONICS
4	2	3	1	1
3	1	4	1	2
2	4	2	2	3
1	3	1	3	4

Best	Worst
1	4

ADVANCED PROPULSION EXPERIENCE

FIGURE 3

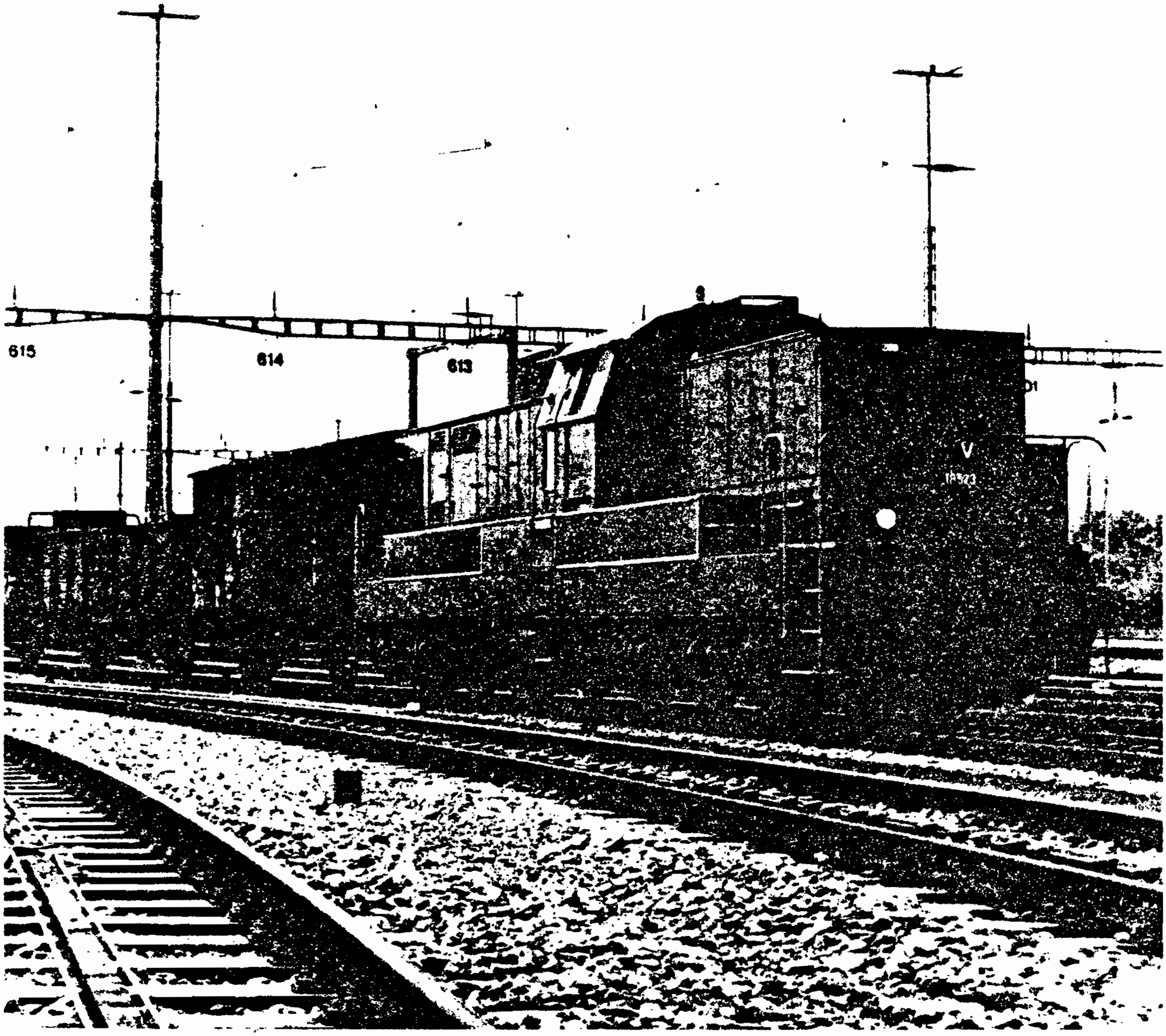
ATTACHMENT A

BBC
BROWN BOVERI

Class Am 6/6 Diesel Locomotives of the Swiss Federal Railways

Publication No. CH-B 0520 E

Offprint from the
Brown Boveri Review No. 12–1977



Class Am 6/6 Diesel Locomotives of the Swiss Federal Railways

M. Roffler, Zurich

Although the network of the Swiss Federal Railways (SBB) is fully electrified, diesel locomotives are needed as a thermal operational reserve to assure train haulage in the event of a power failure on the overhead line, or in times of crisis. Normally, however, they are employed for heavy hump marshalling duties. The present article shows how both tasks can be accomplished by a single type of locomotive, by using static convertors.

Background

Ten years ago, in 1967, Brown Boveri Baden began conversion work on the experimental convertor locomotive Be4/4 (No. 12001) with asynchronous traction motors. For that purpose, the SBB made available a baggage motor-coach type De4/4 dating back to 1928 [1].

In 1970, BBC Mannheim began testing the first of three diesel-electric convertor locomotives class De2500 [2].

In 1972, investigations conducted by the SBB revealed the need for six diesel locomotives for heavy marshalling duties and to act as thermal reserve to assure train haulage in an emergency. The requirements for these fundamentally different types of operation were best satisfied by a traction vehicle equipped with static convertors. Thus, in December 1973, the SBB placed the order for the mechanical equipment of six diesel-electric convertor locomotives class Am6/6 with Thyssen-Henschel, Kassel, the entire electrical equipment being ordered from Brown Boveri Baden and the diesel engines from Chantiers de l'Atlantique [3].

Specifications

The class Am6/6 locomotive was designed to perform two quite different kinds of service:

Fig. 1 Am6/6 locomotive during hump marshalling service

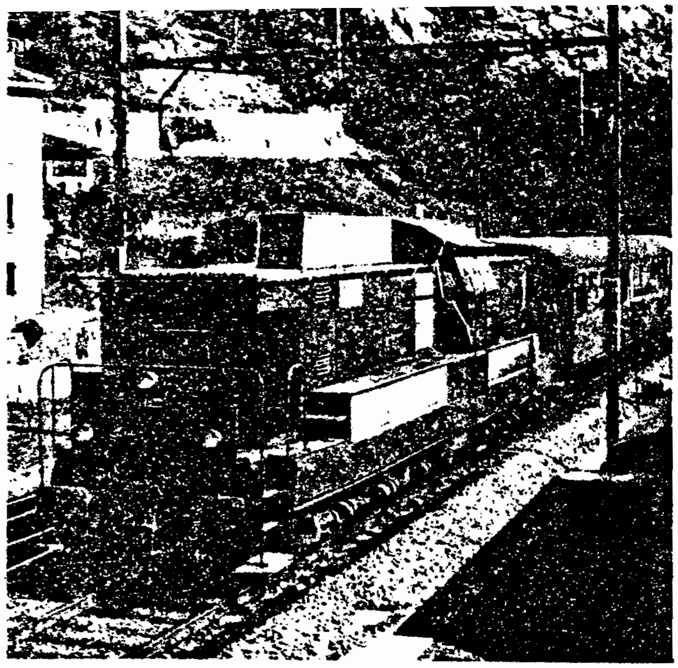


Fig. 2 Am 6/6 locomotive during the heat run on the Gotthard route with the standard trailing load of 700 t

Thermal operational reserve on the Gotthard line and in times of crisis *(Fig. 1)*.
Hump marshalling duties in large marshalling yards *(Fig. 2)*.

These aims determined the essential limiting conditions for the design of the electrical equipment:

- A central driver's cab, minimum vehicle length and maximum visibility *(Fig. 3)*.
- High tractive effort and high top speed with the relatively low power limitation of the diesel engine *(Fig. 4)*.
- All components had to be designed for continuous operation at any desired point on the tractive effort/speed diagram, and especially for maximum tractive effort at standstill (power at the wheel-rim 0).
- To haul a 700 t train over the Gothard route the coefficient of adhesion must not be less than 0·26. For this reason the inverters must be divided between two independent bogie systems.

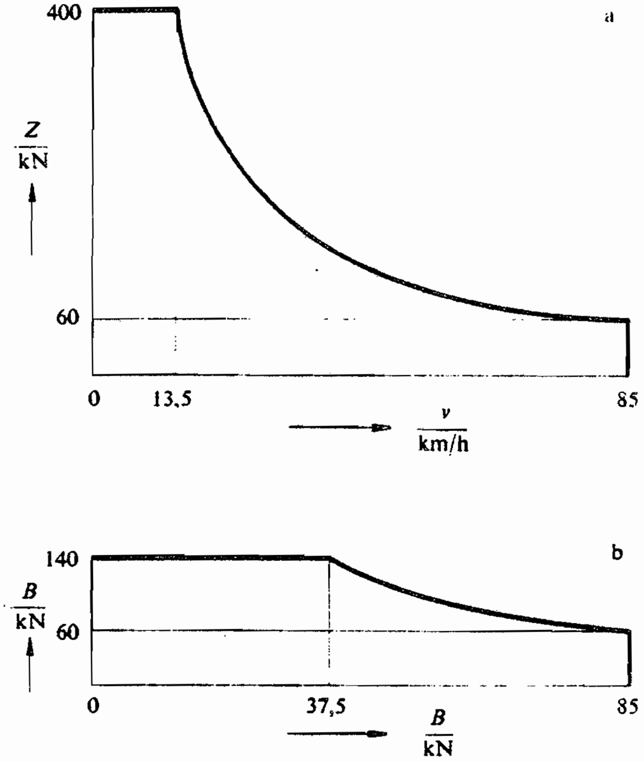
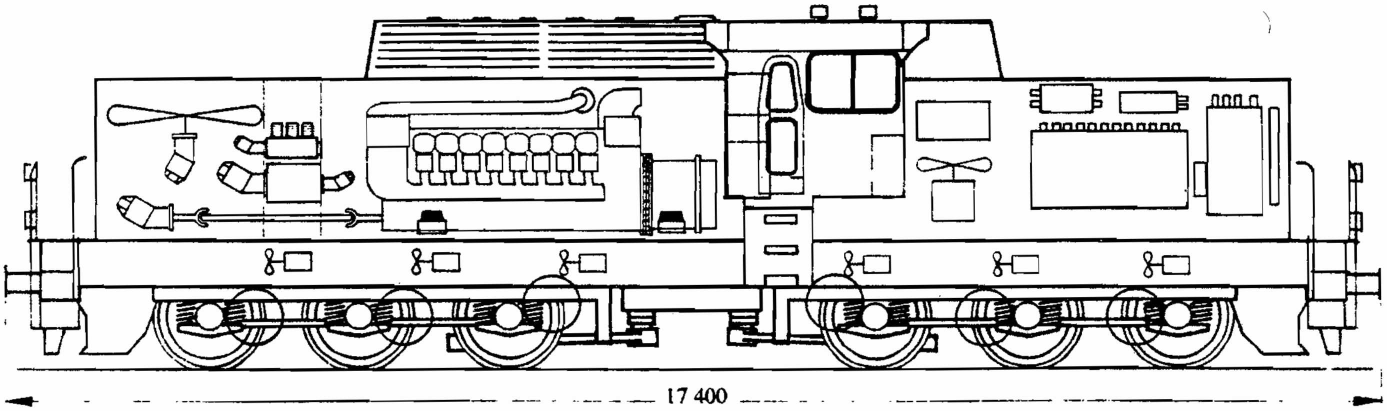


Fig. 4 – Tractive effort/speed diagram
a: Motoring
b: Braking
v Speed
B Braking effort
Z Tractive effort

- The locomotive must have as little effect on the environment as possible. To ensure low fuel consumption, overall efficiency must be as high as possible throughout the entire speed range, but especially at part load.
- The speed of the diesel engine must be completely independent of the speed of travel *(Fig. 5)*.
- High availability, i.e. low susceptibility to disturbances and low maintenance requirements.

Fig. 3 Arrangement of the locomotive. Owing to the central position of the driver's cab, visibility is relatively poor. Hence the dimensions of the body had to be kept as small as possible.



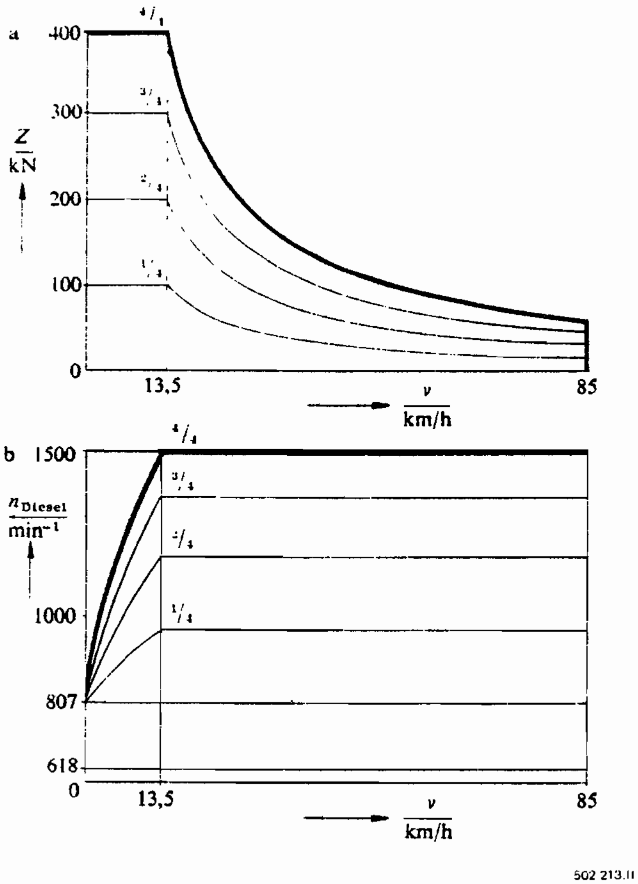


Fig. 5 - Tractive effort/speed diagram (a) and corresponding speeds of the diesel engine (b)

n_{Diesel} - Speed of the diesel engine

v Speed of travel

Z Tractive effort

1/4–4/4 Positions of the driver's handle

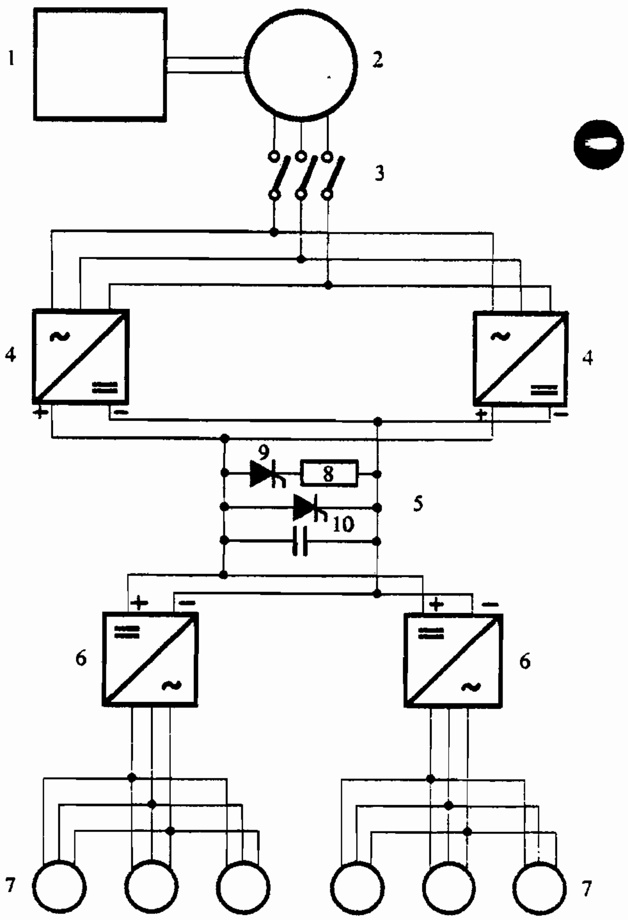


Fig. 6 - Circuit diagram of the electric power transmission system

1 Diesel engine
2 = Generator
3 = Contactors
4 = Rectifiers
5 = Intermediate circuit
6 = Inverters
7 = Traction motors
8 = Brake resistor
9 = Switching thyristor
10 = Shorting switch

- The dielectric strength of all electrical components must be designed to withstand the high humidity at high temperature as encountered in the Simplon tunnel, for example, as well as polluted ambient air.
- The locomotive must be easy to operate, e.g. by engine drivers without any special training.

Basic Concept

The above boundary conditions can be met by a transmission concept using commutatorless machines and static convertors *(Fig. 6)*. The diesel engine 1 drives the direct-coupled brushless main generator 2. This feeds the intermediate d.c. (voltage) circuit 5 via the contactors 3—the only galvanic separation between the generator and the traction motors—and the two rectifiers 4. Here the two inverters 6 are connected with low inductance. Each inverter supplies the three traction motors 7 of one bogie with variable current and variable frequency. The brake resistor 8 together with its switching thyristor 9 and the shorting switch 10 to protect the inverter thyristors is also connected to the intermediate d.c. circuit.

Also bearing in mind the boundary conditions, a design employing a 380 V, 50 Hz inboard network was chosen for the *auxiliaries*. This supply is generated by a separate auxiliary generator driven by the diesel engine via a hydrostatic, constant-speed drive system.

For hump marshalling duties the Am6/6 locomotive is fitted with a speed governor and radio remote control. Maximum possible observance of the cast-off speed demanded by a ground computer or by the yard-master on the one hand, and the demand for maximum overall efficiency even at a low power output level, on the other, necessitated a special control concept, comprising the following circuits.

- Power control: the power at the wheels is controlled to the set value determined by the master controller
- Speed control: the speed is kept at the value given by the master controller or by radio remote control.

Inverter control: the inverters are pulsed in different ways to enable the traction motors to operate at variable voltage and variable frequency according to their speeds, and to ensure that the motor torque corresponds to the value demanded by the power or speed setting.

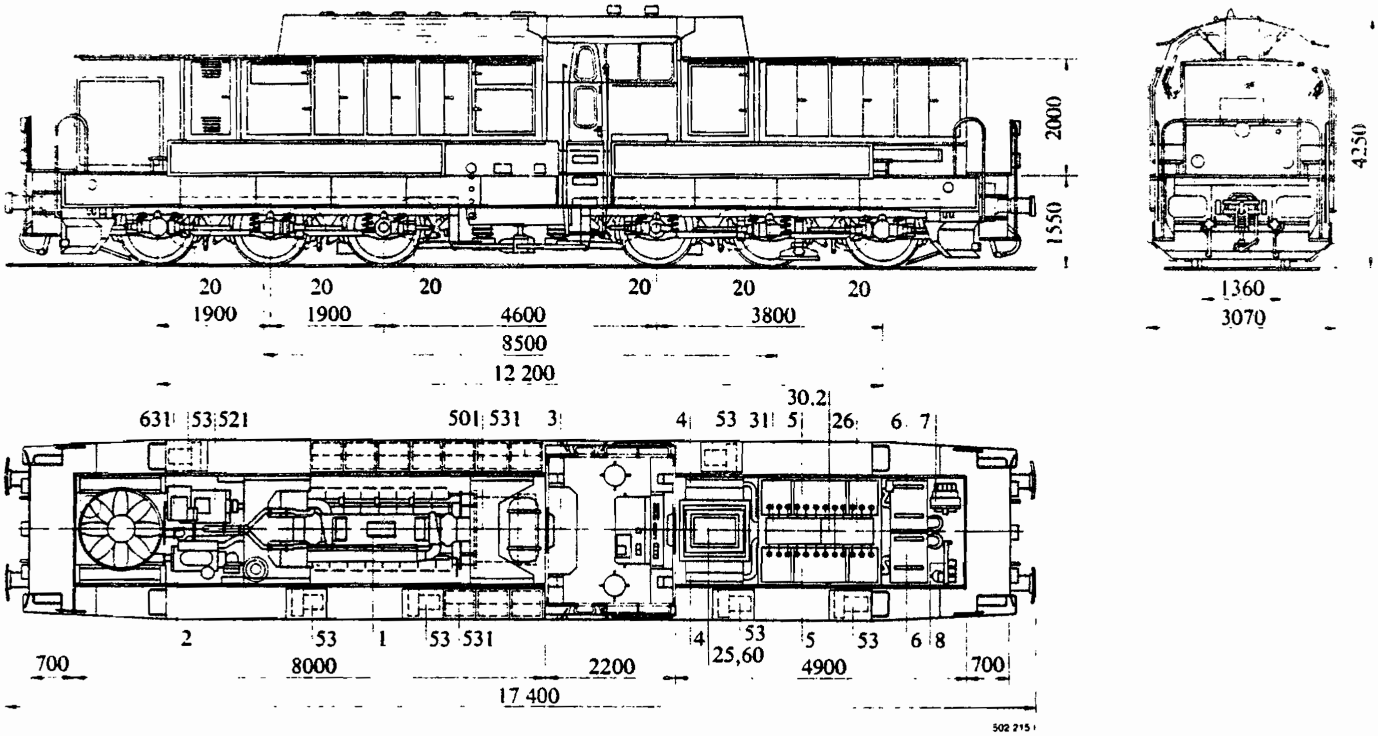
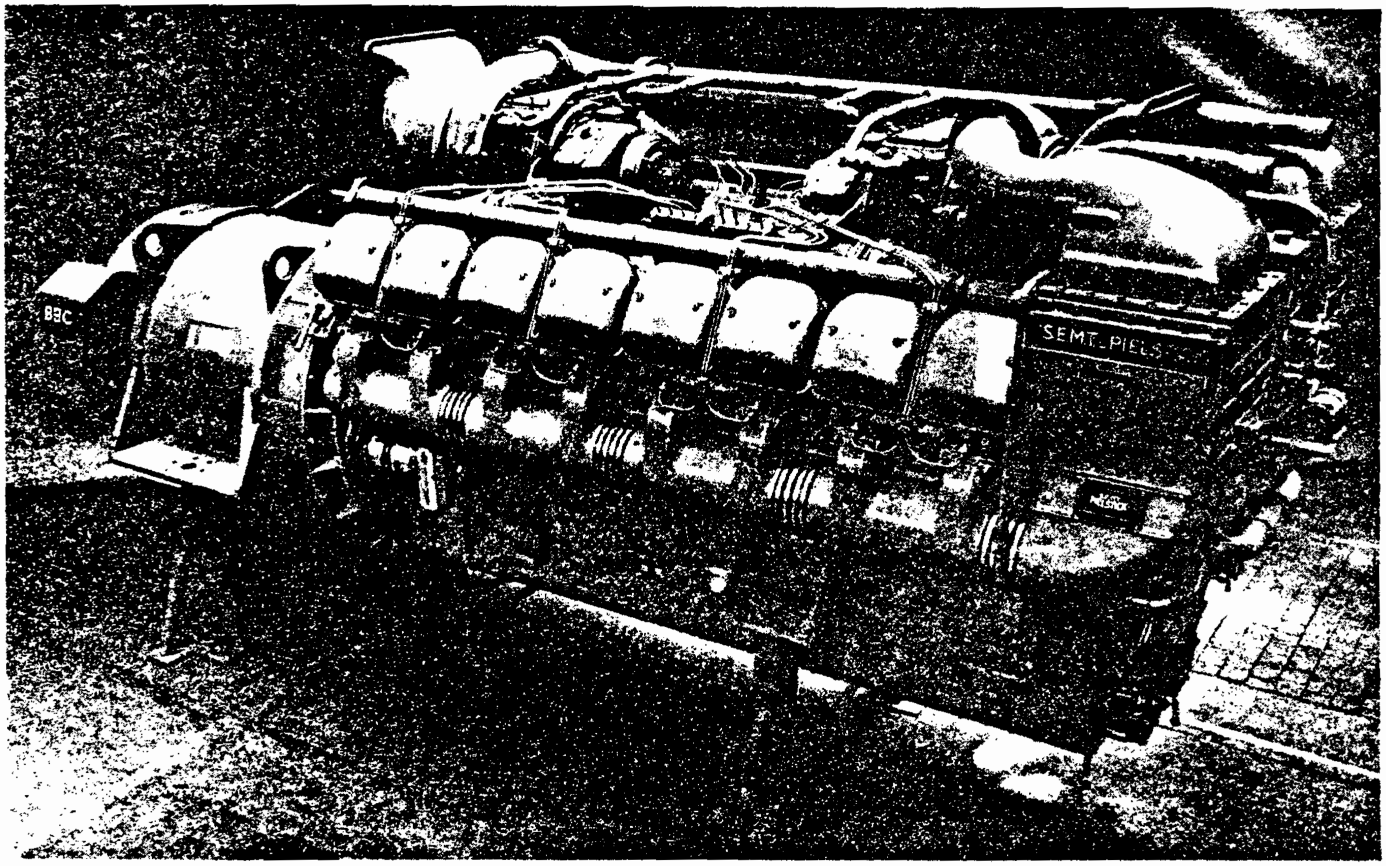


Fig. 7 - Outline sketch of the Am6/6 locomotive

No.	Item
1	Diesel engine
2	Compressor
3	Electronics
4	Oil cooler
5	Inverter
6	Rectifier, brake switch thyristor, in-phase smoothing reactor
7	Contactor, current and voltage transformers
8	Pneumatic equipment panel
20	Traction motor
25	Brake resistor
26	Generator shorting switch
30.2	Back-up capacitor
31	Intermediate circuit shorting switch
53	Traction motor fan
60	Brake resistor fan
501	Main generator
521	Auxiliary generator
531	Starter battery
631	Battery charging generator

Fig. 8 – Diesel engine-generator set



Generator voltage: the voltage of the intermediate circuit is set to a fixed, constant value via the generator excitation, irrespective of the power and generator speed.
- Diesel governor: the diesel engine is set to that speed at which its efficiency is best and, consequently, the fuel consumption is lowest for the power it is momentarily delivering.

Supervision of the locomotive equipment has been designed so as to avoid damage to any power components in the event of fault conditions, as far as possible. Since faults in the inverter lead to a very rapid sequence of events with a high energy content, which may attain the magnitude of a stroke of lightning, sophisticated electronics had to be provided to protect the thyristors by shorting switches in the intermediate circuit.
Having regard to operational simplicity, the following fault conditions are indicated by means of general indicator lamps:

- Fault in the diesel engine
- Fault in the electronics
- Fault in the auxiliary system

If one of these three indicator lamps lights up, a corresponding control panel in the driver's cab can be opened and the fault localized there with the aid of precisely assigned fault lamps and, if need be, individual groups of equipment can be disconnected. Thus, limited emergency operation is possible in the event of a fault.

Technical Data of the Locomotives

Class Am6/6 No. 18521–18526	
Axle sequence	Co'Co'
Weight in service order	111 t
of which electrical equipment	31 t
Number of traction motors	6
Transmission ratio	1:7·69
Max. tractive effort at wheel-rim	400 kN
in a speed range	0–13·5 km/h
Continuous tractive effort at wheel-rim	400 kN
in a speed range	0–13·5 km/h
Power output of diesel engine	1840 kW
at	1500 rev/min
Max. power output at wheel-rim	1500 kW
Continuous power at wheel-rim	1500 kW
Max. electrical braking effort	140 kN
in a speed range	0–37·5 km/h
Top speed	85 km/h
Trailing load on Gotthard route (gradient 1 in 38)	700 t
Outline sketch	Fig. 7

Components of the Main Current Circuit

The *main generator* is a single-bearing, three-phase synchronous machine. The stator is bolted direct on to the housing of the diesel engine. The rotor is connected to the crankshaft via an elastic-torque clutch, the crankshaft bearing constituting at the same time the drive-end bearing for the rotor. This design ensures the shortest construction length for the entire set *(Fig. 8)*.

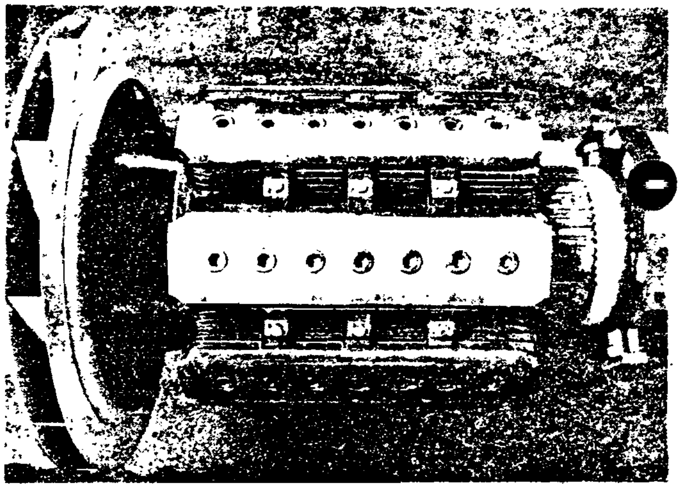


Fig. 9 – Generator rotor

Technical data:

Type designation	WGTh 630qa8
Number of poles	8
Speed at full load	1500 rev/min
Frequency at full load	100 Hz
Minimum operating speed	807 rev/min
Power output	1725 kVA
Voltage	1221 V
Current	816 A
Power factor	0·97
Insulation class	F
Weight	4455 kg

The generator is so designed that the full voltage of the intermediate circuit can also be attained at minimum operating speed. The full voltage is necessary at standstill to assure commutation of the starting current in the inverters (power at wheel-rim = 0). The current load, on the other hand, diminishes owing to the speed of the diesel engine being decoupled from that of the traction motors at decreasing speed, with the result that—in contrast to conventional diesel-electric drive systems—it only needs to supply the rated current at full speed. It was therefore possible to design the generator as a self-cooled unit, the air being drawn in frontally at the non-driving end and expelled into the diesel compartment by the radial fan at the driving end. The intake chamber and the diesel compartment are separated by a bulkhead. The generator cooling air here also serves to cool the exhaust silencer. In elaborating the mechanical design, the protection concept with shorting switches meant that due consideration had to be given to insulation against short circuits.
The brushless 15·5 kVA generator, the rotating excitation rectifier and the generator rotor are telescoped on account of the limited length of the locomotive *(Fig. 9)*.
The *rectifiers* are two separate, three-phase diode bridges. Each bridge is proof against short circuits and is designed to take double the voltage. Consequently, it is possible to drive at full power even when one diode is faulty. The rectifiers are installed in an oil-filled tank together with other units.

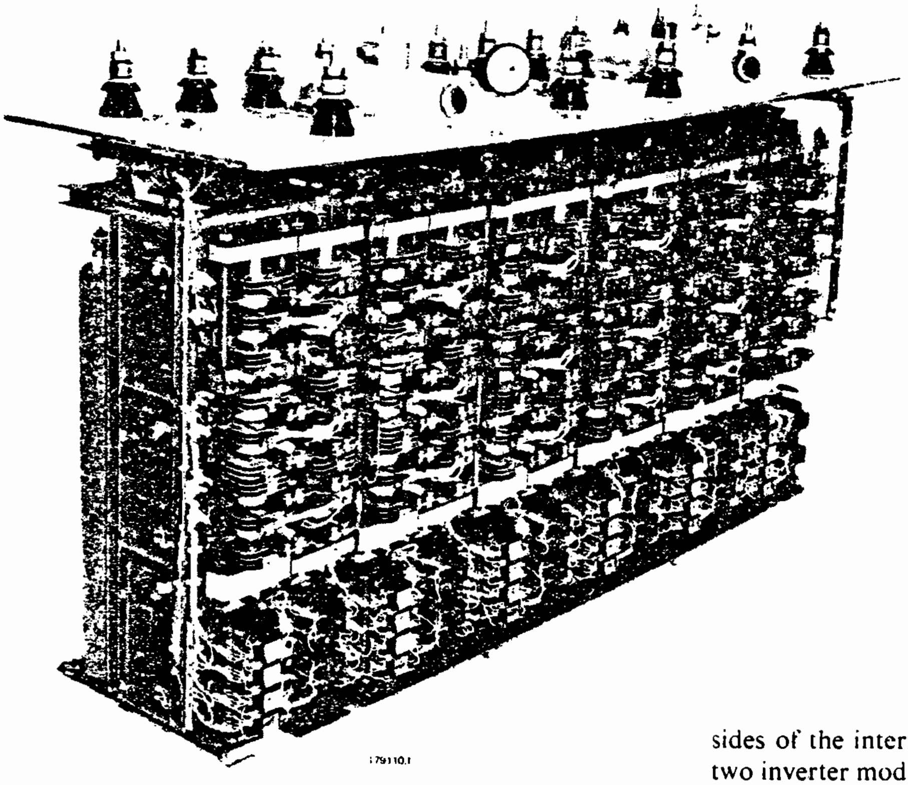


Fig. 10 – Three-phase, two-pulse inverter before insertion in its oil tank

The *back-up capacitor* in the intermediate d.c. circuit has the task of smoothing the voltage ripple of the rectifier and of supplying the reactive power for inverter switchover and traction motor excitation. The optimal point between permissible ripple voltage in the intermediate circuit, on the one hand, the space occupied and the current to be controlled in the event of a short circuit, on the other, is at a capacitance of 23 mF. The capacitor bank, consisting of 18 elements, is installed between the two inverters. This ensures the shortest possible connections to the inverter modules.

Two *shorting switches* are mounted above the capacitor bank. The shorting switch of the intermediate circuit is designed so that, in the event of a fault in an inverter, it can accept a sufficient proportion of the capacitor discharge voltage to ensure that the inverter thyristors suffer no damage. Disconnected from this very rapid discharge process by a choke, the generator shorting switch receives the generator short-circuit current, increasing about 100 times less rapidly and thus, in the event of a fault, it relieves the overheated thyristors of the intermediate circuit shorting switch and the inverter.

The two three-phase, two-pulse *inverters,* each assigned to one bogie, are immersed in oil *(Fig. 10).*

Technical data:

Input d.c. voltage	1500 V
Output voltage	0–1350 V
Output current (r.m.s. value of fundamental)	400 A
Max. current that can be commutated	1000 A
Output frequency (fundamental)	0–100 Hz
Max. clock frequency	190 Hz
Weight	1300 kg

For ease of understanding, each inverter module may be considered as an electronic changeover switch which connects the output alternately to the positive and negative sides of the intermediate d.c. circuit. One output each of two inverter modules are connected together via a traction motor winding and a winding of the identically phased smoothing reactor. Three such pairs of modules constitute a three-phase, two-pulse bogie inverter.

The inverters operate in two basically different modes:

- In the sub-harmonic mode in the speed range 0–13·5 km/h [4]
- In the fundamental mode at speeds between 13·5 and 85 km/h

In the *sub-harmonic mode* modulation of the pulse width creates the motor voltage, variable in frequency and amplitude. Here the clock frequency of both inverters remains constant at 190 Hz. The changeover time of the electronic switches cannot be reduced indiscriminately. This results in a minimum pulse width or pulse gap. This is why, in sub-harmonic mode, the voltage of the traction motor can only be raised to 85% of the amplitude theoretically obtainable with infinitely narrow pulses or gaps.

If this limit is reached, operation is switched over to the *fundamental mode.* During the process of switching over, the motor voltage must not jump, either in fundamental amplitude or in phase angle. To this end, in the fundamental mode, the motor-frequency voltage blocks of the two series-connected inverter modules are mutually offset in time. This permits the amplitude of the voltage fundamental to be modified continuously up to its full extent.

Since the clock frequency is lowest immediately after the changeover to fundamental mode—it is the same as the motor frequency which is approx. 15 Hz—the harmonic currents are largest at this point. This aspect has to be taken into account in the electrical design of the inverters, the in-phase smoothing reactors and the traction motors.

The design and layout of the inverters were determined primarily by the specified requirements for large tractive effort at low speeds in continuous operation, high dielectric strength, freedom from maintenance and good visibility for the driver. Because of the numerous live components in the inverters, the only design that could be considered was one that has proved its worth often

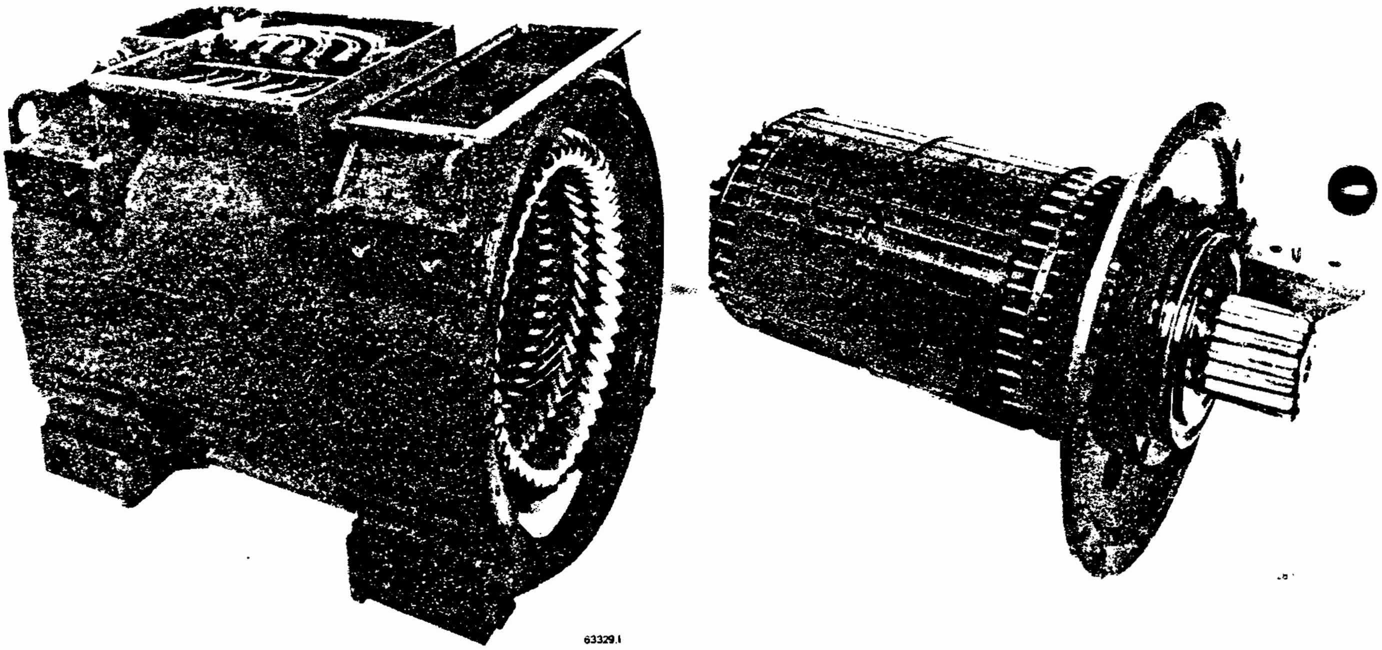


Fig. 11 Asynchronous traction motor
Left: Stator
Right: Rotor

enough in the past, i.e. the oil-immersed static convertor that has been employed by Brown Boveri since 1972 [5].

The greater difficulty in replacing thyristors compared with an air-cooled design is not a drawback, because with the protection concept employed, thyristor defects hardly ever occur any more. In oil-cooled static convertors, leakage and earth capacitances are considerably larger than in air-cooled designs since, on the one hand, the distance between live parts is smaller and, on the other, oil has a much higher dielectric constant than air. For this reason it was necessary to pay careful attention to mutual interference. For the electrical design, the best compromise had to be found between the contradictory demands of high efficiency and small dimensions of the traction motor, on the one hand, and low losses and bearable costs for thyristors and switching elements in the inverter, on the other, while naturally complying with the limiting conditions of the specification.

The inverters, as incidentally are the bogies too, are interchangeable with those of the ten Ee6/6 II all-electric convertor locomotives ordered by the SBB and due to be delivered in 1979. In the event of a defect, both a complete inverter and an individual module can be changed with relatively little effort, enabling the faulty part to be repaired and tested in the workshops. In the event of a thyristor defect, for example, the locomotive is not immobilized in the depot for more than 8 hours.

The *asynchronous traction motors* are of nose-suspended design *(Fig. 11)*.

Technical data:

Type designation	4 FRA 3069
Number of poles	4
Maximum speed	3000 rev/min
Continuous output at the shaft	250 kW
Voltage	1350 V
Current	123 A
Max. torque at shaft	5300 Nm
in a speed range	0–450 rev/min
Stator frequency	0–100 Hz
Slip frequency at max. torque (warm)	0·7 Hz
Stator insulation	class H
Weight	1795 kg

As regards the electrical design, the best compromise had to be found to accommodate the requirements for maximum possible leakage inductance to limit current h[illegible]monics, sufficiently high pull-out torque at reduced fl[illegible], large machine slip, low power losses and light weight [6].

Since, with minimum adhesion of 26% for all axles when hauling a 700 t train on the Gothard slope, uniform distribution of the load between the six traction motors cannot be guaranteed—with a speed difference of 2% the torque of the fastest motor is zero—it was necessary to thermally underrun the traction motors. Thus, it is possible to produce the tractive effort for starting, 400 kN, continuously, this having been impressively demonstrated when a constant tractive effort of over 400 kN was recorded over a period of one hour against the buffer block.

The mechanical design was determined by the torque during short circuit and the high transmission ratio of 1:7·69. For the same reason the nose-suspended drive had to be designed to permit torsional elasticity *(Fig. 12 and 13)*.

For the two-pulse inverter circuit the traction motors are designed with open windings, i.e. the phase windings are not connected to one another. It would in that case be possible for in-phase harmonic currents to flow in the traction motor, since Kirchhoff's law cannot be applied. In order, nevertheless, to suppress these in-phase harmonic currents (of the 3rd, 9th, 15th, 21st... order) in-phase smoothing reactors were connected in series with the windings of the traction motors. The three windings [illegible] each reactor are ideally coupled with each other and th[illegible] exhibit very high impedance for suppressing the in-phase harmonic currents.

The independently cooled high-power *brake resistor* is connected to the intermediate circuit and is cut in by thyristors instead of by contactors 7.

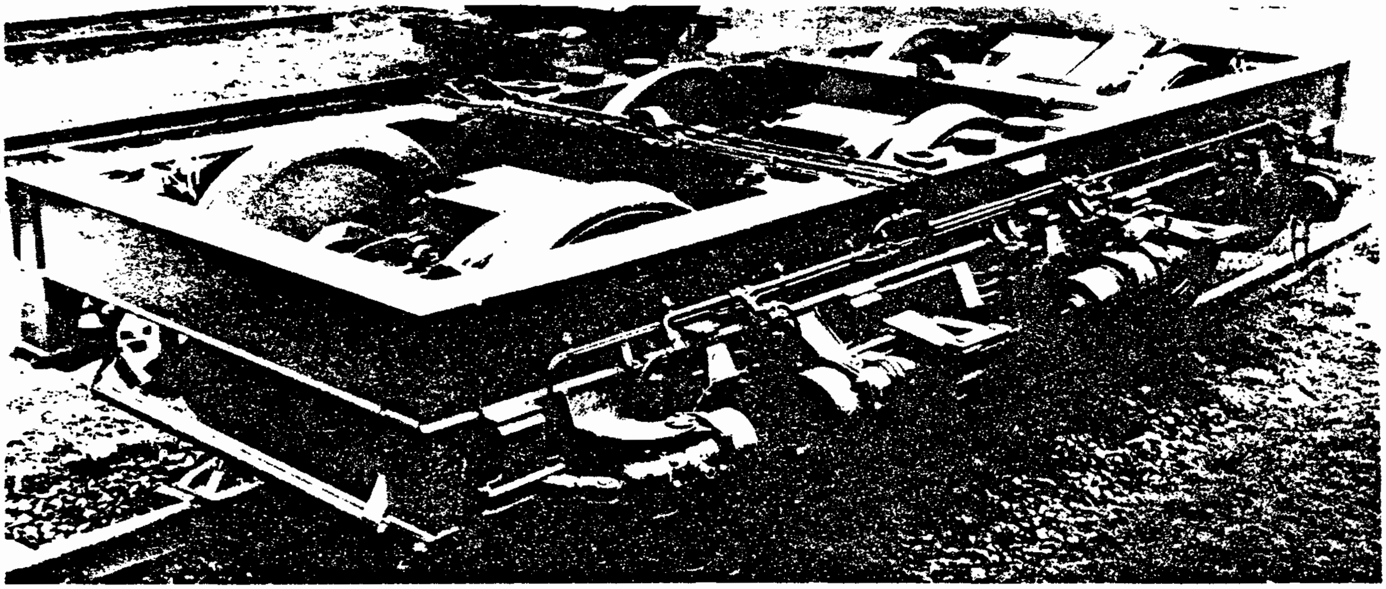


Fig. 12 - Bogie with built-in traction motors

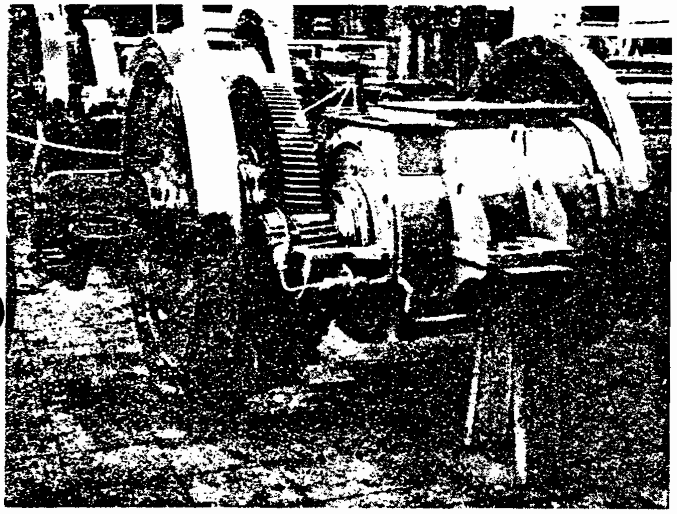


Fig. 13 - Wheel set with traction motors and drive

Technical data:

Power rating	1440 kW
Resistance	1·57 Ω
divided between 4 parallel resistance elements each of	6·28 Ω
Required cooling air flow	7·5 m³/s

The braking effort at the wheel-rim is equal to the tractive effort (see Fig. 4).

In addition to its normal purpose, the brake resistor is also used to discharge the capacitance of the intermediate circuit on switching off and for the occasional operation of the diesel engine at full power. This allows the deposits in the exhaust system of the diesel engine, accumulated by continuous operation at part load in hump duties, to be burnt off.

For test purposes the brake resistor can absorb about 90% of the total power output of the diesel engine.

Components of the Auxiliary System

The fan of the radiator cooling the diesel engine is driven by a system of hydrostatic pumps and motors. This system also serves to generate the inboard auxiliary supply of 380 V, 50 Hz, a swivel-mounted hydromotor driving a *self-cooled auxiliary synchronous generator* at constant speed *(Fig. 14)*.

Technical data:

Type designation	WP 280S4A
Number of poles	4
Speed	1500 rev/min
Rated output	90 kVA
Voltage	400 V
Current	130 A
Power factor	0·9
Insulation	class F
Weight	686 kg

The auxiliary generator is self-excited via a compound transformer and a three-phase rectifier bridge.

Asynchronous motors are connected to the 380 V, 50 Hz a.c. inboard network to drive the following units:

- 6 fans for cooling the traction motors
- 1 fan for cooling the brake resistor and oil cooler
- 2 oil pumps
- 2 fans for the driver's cab, as well as
- 3 resistors for heating the cab electrically

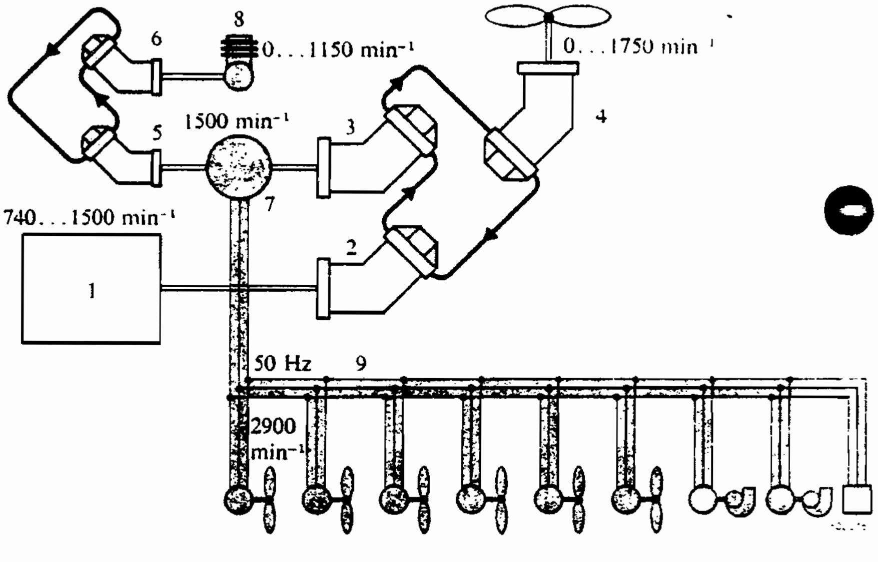
The 120 V starter battery is recharged by a claw-pole synchronous generator with an output of 10 kW, driven direct by the diesel engine by a V-belt *(Fig. 15)*. The battery possesses a 36 V terminal to which all the control and power supply elements of the electronic control system are connected.

Open and Closed-Loop Control

The *locomotive control system* comprises a number of cascaded control circuits *(Fig. 16)*.

Fig. 14 Arrangement of the auxiliaries

1 Diesel engine
2 Hydraulic pump
3 Hydraulic motor for auxiliary generator
4 Hydraulic motor for fan of water cooler
5 Hydraulic pump
6 Hydraulic motor for compressor
7 Auxiliary generator
8 Compressor
9 Inboard a.c. network 380 V, 50 Hz



When the mode selector switch is set to 'Normal' the power control loop has overriding priority. Up to a speed of 13·5 km/h a tractive effort Z_W proportional to the handle setting of the master controller is produced. At higher speeds the engine driver calls for a definite power at the wheel P_W by varying the setting of the master controller. The controlled variable of the power control loop is the slip frequency f_s of the motor. The desired output may be limited under certain conditions:

- If the diesel engine is cold, its speed and hence its power output will be restricted.
- During dynamic control actions the diesel engine must be protected against overloading.

Even if the diesel engine is occasionally operated at full output during hump marshalling, causing part of the brake resistor to be cut into the intermediate circuit, the power control loop limits the tractive effort, if necessary.

- When the anti-slip relay operates, power is briefly cut back.

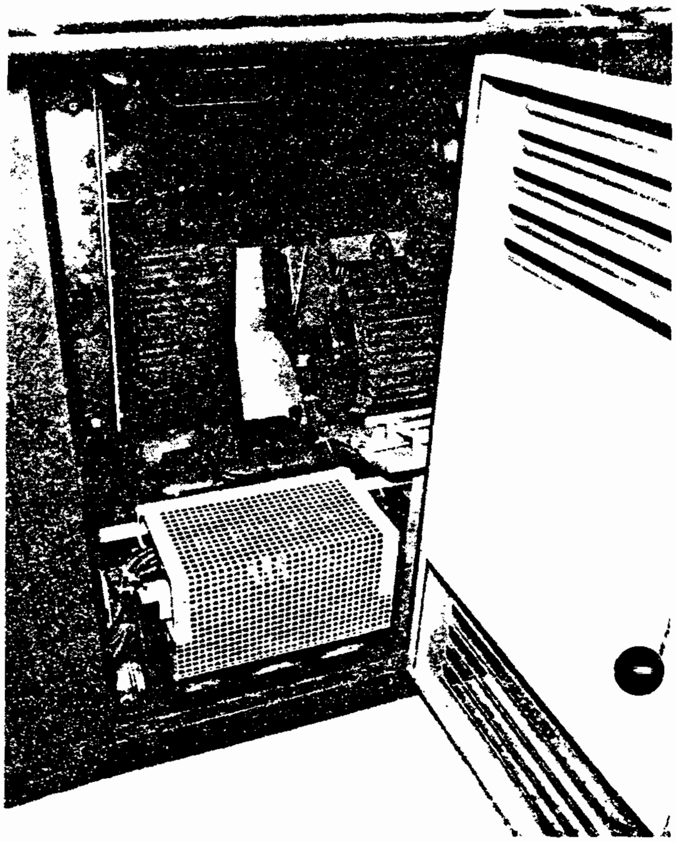
In the same manner the master controller can also be used to obtain an electric braking effort although, because of the maximum admissible buffer pressures, the braking effort is limited to 140 kN. If the speed of the locomotive is less than 15 km/h, a solenoid valve releases the compressed air controlled by the same master controller to the brake cylinders. To ensure smooth transition from electric to pneumatic braking a pressure transducer reduces the nominal value for the electric brake (P_W). Although the latter brake may certainly be used to brake to standstill, at low speeds the pneumatic brake is used so that the wheel tyres are cleaned by the cast-iron brake blocks.

With the mode selector switch on 'Hump operation', the engine driver sets a desired speed by shifting the master controller: this is the cast-off speed. Here again, the *speed governor* controls the cast-off speed of the train over the hump via the slip frequency f_s, which acts as controlled variable in the speed range between 0 and 20 km/h. Since the train's couplings are not always attached, the brake cannot be involved in the process.

The position of the mode selector switch 'Radio remote control' has the same significance for the control of the locomotive as the 'Hump operation' position, the desired speed v_W being given, not by the master controller but by the signalbox computer or the yard-master by means of a radio code converted by an adaptor.

The following measures assure *maximum possible adhesion* for this drive concept under any rail conditions.

Fig. 15 – Auxiliaries compartment with compressor, battery charging generator and auxiliary generator



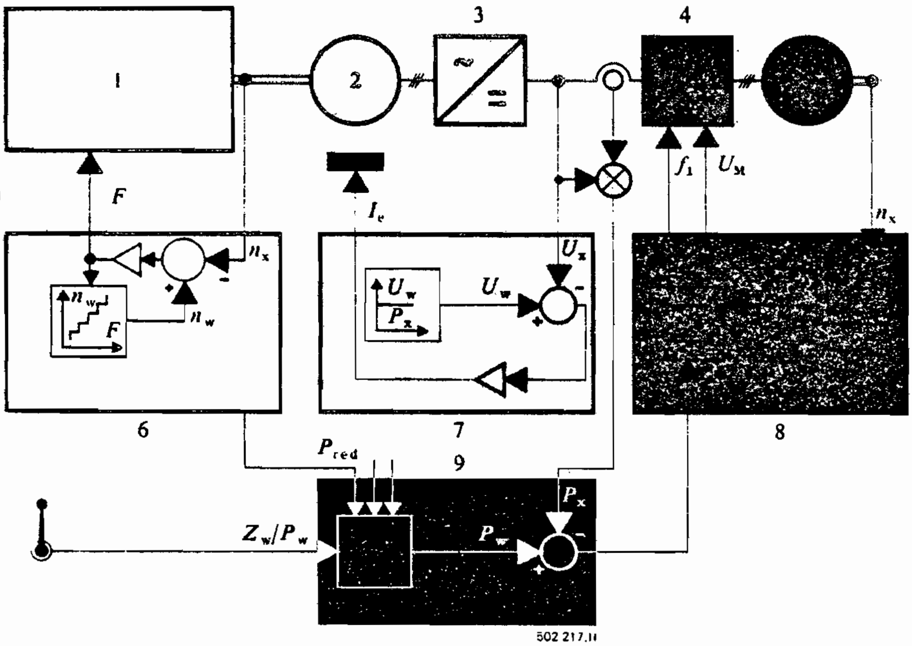


Fig. 16 – Schematic diagram of the locomotive control system

1 = Diesel engine
2 = Generator
3 = Rectifier
4 = Inverter
5 = Traction motors
6 = Diesel engine governor
  n_w = Desired speed
  n_x = Actual speed
  F = Filling
  P_{red} = Power reduction signal
7 = Generator regulating circuit
  I_e = Excitation current
  P_x = Power output
  U_w = Desired voltage
  U_x = Actual voltage
8 = Inverter control
  f_1 = Fundamental frequency of traction motor voltage
  f_m = Frequency of rotation of traction motors
  f_s = Slip frequency of traction motors
  n_x = Speed of traction motors
  U_M = Voltage of traction motors
9 = Power control
  P_w = Desired output
  P_x = Actual output
  Z_w = Desired tractive effort

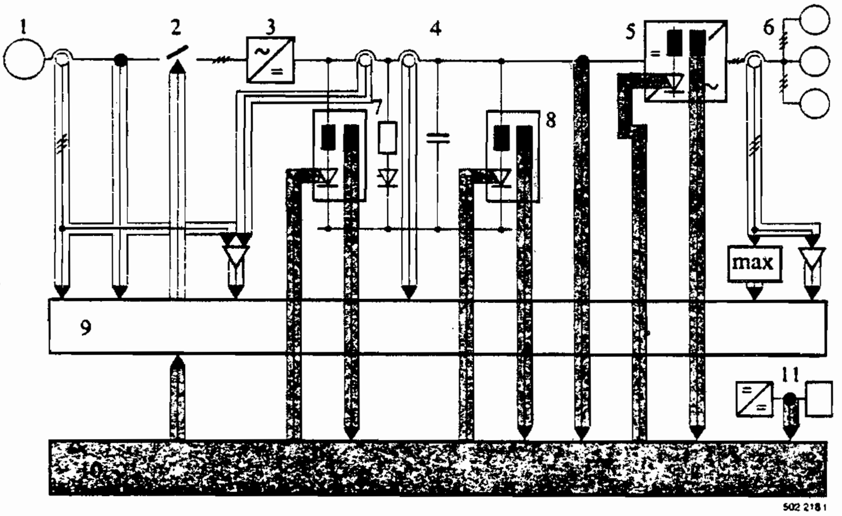


Fig. 17 – Supervision of the electric power transmission system

1 = Generator
2 = Contactors
3 = Rectifier
4 = Intermediate circuit
5 = Inverter
6 = Traction motor
7 = Generator shorting switch
8 = Intermediate circuit shorting switch
9 = Limit value monitor
10 = Inverter protection
11 = Electronic power supply

- Reduction of the load on one of the axles within the bogie is virtually excluded since the tractive efforts are transmitted via bars fitted well below the bogie.
- The trailing bogie exerts a tractive effort that is 10% higher than that of the leading bogie.
- If there is a difference in speed between the traction motors, the torque is very rapidly and briefly reduced in an initial stage.
- In a second stage, the anti-slip brake acts on each bogie selectively.
- If any of the traction motors accelerates at more than a definite rate, torque is reduced for a longer period in order to prevent all axles from slipping.

The most complex and expensive item of electronic control equipment on the locomotive is the *inverter control system.* In itself, it consists of a number of cascaded circuits. Its reference input is a control voltage (U_M, f_1) from which, by comparison, the timing pulses for the inverter thyristors are formed from an auxiliary control voltage in the gate control set. The control voltage is proportional to the traction motor voltage, both in frequency and amplitude. The frequency f_1 of the traction motor voltage, and thus also of the control voltage, is the result of adding or subtracting the slip frequency f_s to or from the frequency of rotation f_m. The latter frequency is formed in a rotor frequency generator n_x coupled to the axle of the motor. At speeds between 0 and 21 km/h the amplitude of the control voltage U_M is proportional to f_1. This means that the motor is always fully excited. At higher speeds the amplitude of U_M remains constant since the inverter is operating at its limit. Only the motor frequency f_1 changes. Since in this range the machine flux diminishes with increasing frequency, we speak of the field-weakening region.

Within the inverter control system various current regulators are active:

- A momentary current regulator ensures that the alternating current is as symmetrical as possible in the lowest frequency range.

A d.c. regulator eliminates any d.c. components that occur.

A current amplitude regulator ensures that the traction motors run at every point with the minimum current necessary to produce the required torque.

A further device ensures that the influence of the temperature of the traction motor rotors is compensated. For this purpose temperature sensors are installed in the motors.

The *generator regulator* is autonomous and controls the intermediate circuit voltage to a constant value of 1500 V via the excitation of the exciter. For the electric brake the actual value is derived, not from the intermediate d.c. circuit but from the a.c. side of the rectifier. It corresponds to an intermediate circuit voltage of only about 800 V, which is necessary for the reliable operation of the inverter. If, during electrical braking, the intermediate circuit voltage is higher than this supporting voltage, the generator is disconnected from the intermediate circuit by the rectifier. In special cases the desired value of the intermediate circuit voltage is reduced by a signal from the governor of the diesel engine, so as to protect the engine against overloading.

The *electronic diesel governor,* together with a Woodward mechanical governor, ensures that the overall efficiency of the diesel-electric power transmission system is as high as possible, i.e. that fuel consumption is a minimum at all operating points of the locomotive. The Woodward governor, as subordinate control element, controls the diesel engine via the filling F as controlled variable to the speed n_W given by the electronic diesel governor. This desired speed is calculated at any time by a function generator in which the optimal consumption curve is programmed, from the filling F and the desired speed n_W. In a further function generator the output limiting signal is derived, if necessary, from the filling F and the actual speed n_X, and this signal is passed on to the power control loop.

Supervision and Fault Indication

The supervisory and fault indication functions for the locomotive equipment are divided into three groups:

- Diesel engine
- Electronic circuitry
- Auxiliaries

The diesel engine is supervised by means of pressure, level and speed monitors which keep a check on the water cooling and lubrication systems as well as the speed of the engine.

Supervision of the electric power transmission equipment is divided between electronic limit value monitors and electronic protection of the inverters *(Fig. 17)*. The following values are determined by the *limit value monitors* and actuate the contactors between generator and rectifier, and also cause the general indicator lamp 'Electronic fault' to light up.

- Overcurrent in each phase of the generator
- Overvoltage at the generator
- Current difference between input and output of the rectifier (e.g. due to a defective diode)
- Overcurrent in the intermediate circuit

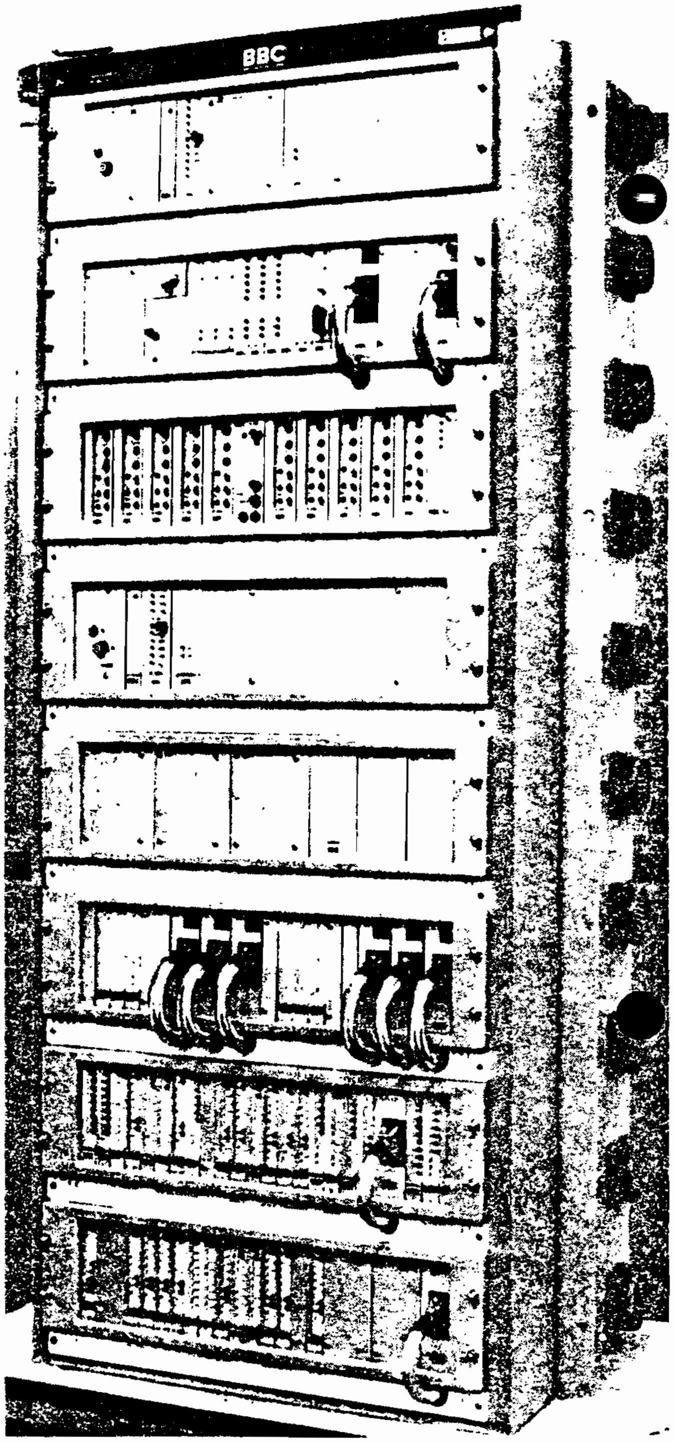


Fig. 18 Electronic block with inverter protection (second row from top), limit value monitors (third row from top) and inverter regulation for one bogie (three bottom rows)

- Undervoltage in the intermediate circuit with the contactors closed
- Earth fault
- Current flowing in the brake resistor when the ventilation is switched off
- Absence of supply voltage for the electronic control circuits
- Overcurrent in the inverters
- Difference in current between the traction motors

The individual causes of tripping are indicated by light-emitting diodes (LED) on the appropriate limit value

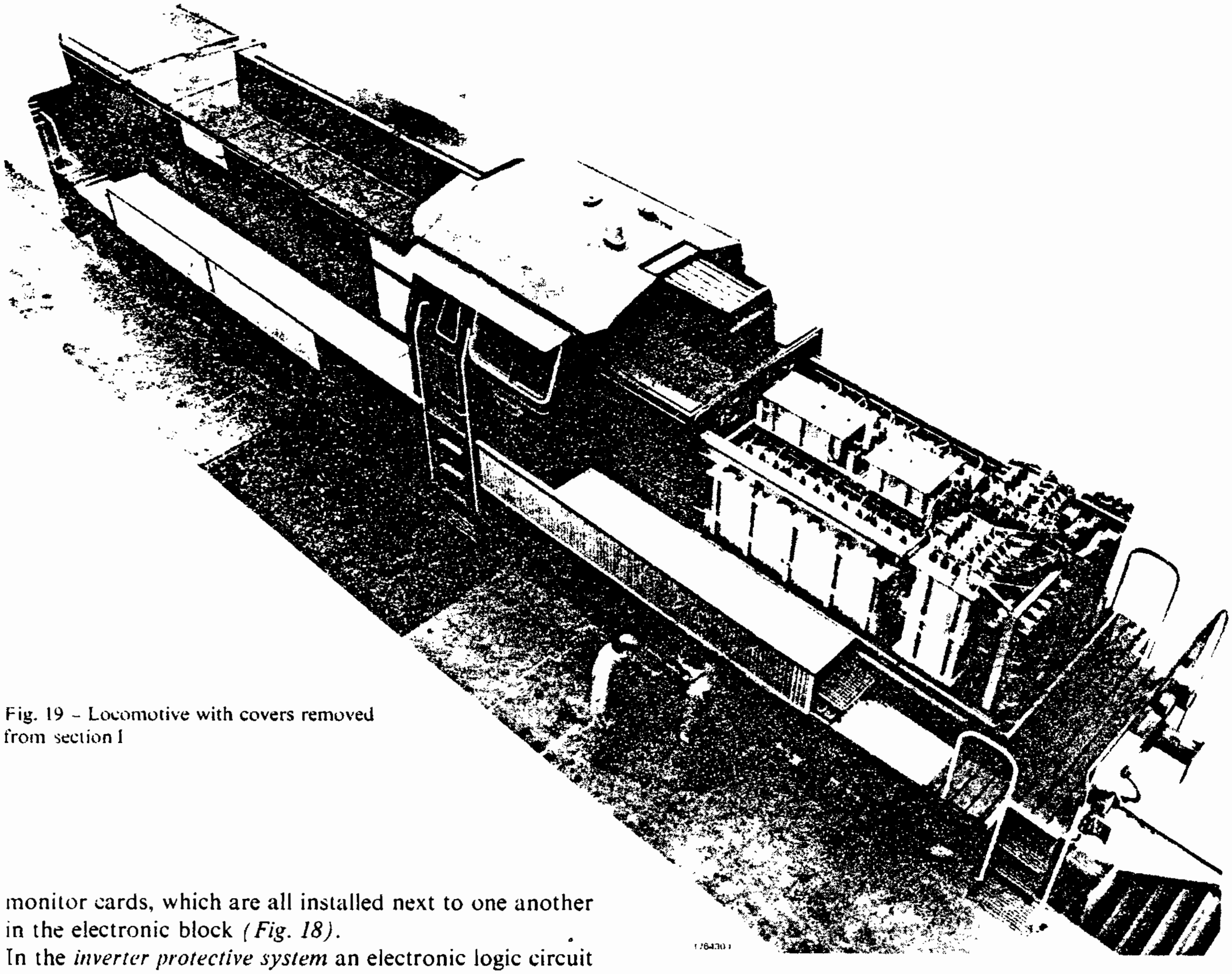


Fig. 19 – Locomotive with covers removed from section I

monitor cards, which are all installed next to one another in the electronic block *(Fig. 18)*.

In the *inverter protective system* an electronic logic circuit processes the following fault conditions, which are determined by special transducers:

- Arc-through in one of the twelve inverter phases
- Arc-through in one of the ten shorting switch circuits
- Overvoltage in the intermediate circuit
- Failure of the power supply to the electronic equipment

With each of these fault conditions very rapid intervention is necessary because of the back-up capacitance being closely coupled to the thyristor circuits. For this reason all the thyristors in the intermediate circuit, i.e. the shorting switch and inverter circuits, are made to turn on not later than 60 µs after the appearance of a faulty condition. By this means it is possible to keep the current in the arc path within permissible limits and to prevent destruction of the thyristors. Simultaneously the contactors are also tripped, though they only begin to open after a period 1000 times longer. When a fault condition is detected, an LED assigned to the primary cause of the fault lights up and any further fault read-in is prevented. This makes it possible to determine the primary cause of the fault at a later stage, in spite of the rapid sequence of events.

Layout of Equipment and Driver's Cab

Except for the generator and traction motors the power transmission elements are accommodated in section I of the vehicle *(Fig. 19)*. On account of the driver's cab being in a central position, it was necessary to aim at keeping the design as compact as possible, though always bearing in mind the SBB requirement that every component should be accessible for removal without first having to dismantle another unit. Symmetrically arranged with respect to the longitudinal axis, from front to rear, are the following units: one equipment block on each side, the rectifier tanks including the in-phase smoothing reactors, the inverter tanks with the back-up capacitor bank between them, and the two oil coolers with the brake resistor and its fan between them. The two shorting switch tanks are mounted above the capacitor of the intermediate circuit.

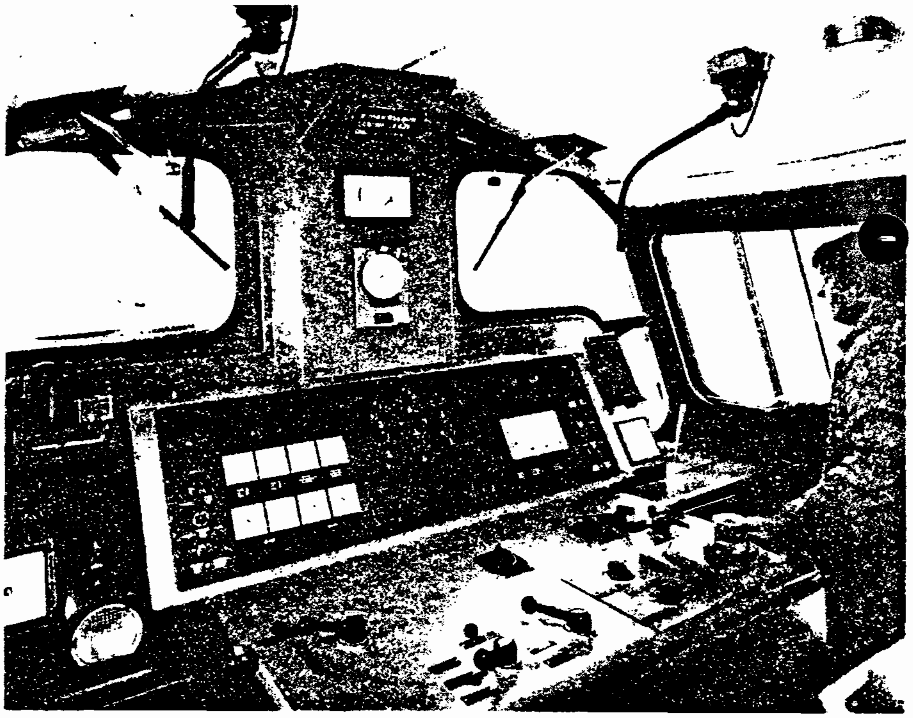
When planning the layout of the driver's cab, special attention was paid to good visibility, spatial conditions and ease of operation *(Fig. 20)*.

The cab has controls on both sides so that the locomotive can be easily driven in either direction. The most frequently used control elements, such as the master controller, the switch for selecting the direction of travel, the sanding button, the microphone key, anti-slip brake key, brake release switch, windscreen wiper control and the toggle switches for cab heating, lighting and ventilation, are all duplicated. The most important instruments, such as pressure gauges for the brakes and the track speed indicators, are also duplicated, while the speed indicators for very precise indication (0 20 km/h) are actually present in quadruplicate.

Fig. 20 Driver's cab

In the foreground, from left to right: Master controller selector switch for direction of travel, mode selector switch, diesel engine control switch, cock for spring-assisted brake, cock for driver's brake valve, automatic brake; at the rear: Control switches for lighting, compressor and pneumatic brake.

The instruments indicate, from left to right: Exact speed, operating temperature of diesel engine, auxiliary voltage; below: Battery charging currents and voltages. In the centre panel: Pneumatic instruments and speedometer; right: Diesel engine speed, voltage of intermediate circuit, inverter currents for both bogies and, again, exact speed indicator.



Initial Operational Experience

Following comprehensive commissioning trials and design verification, Am6/6 locomotives have been in regular service since May 1977, to the entire satisfaction of the personnel involved. Since the ten Ee6/6 II electric convertor locomotives ordered by the SBB are designed with exactly the same bogies but, owing to their limited operational program (no main-line duties), have a lower power rating and consequently only one inverter for all six axles, the behaviour of the drive temporarily connected in this manner was the subject of exhaustive investigations on one of the Am6/6 locomotives.

A heat run with the standard trailing load of 700 t, as for the Gotthard line, was carried out on a warm summer's day between Erstfeld and Giubiasco (in both directions), the results showing that the Am6/6 is able to satisfy these requirements too.

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ATTACHMENT B

BBC-3

BROWN BOVERI

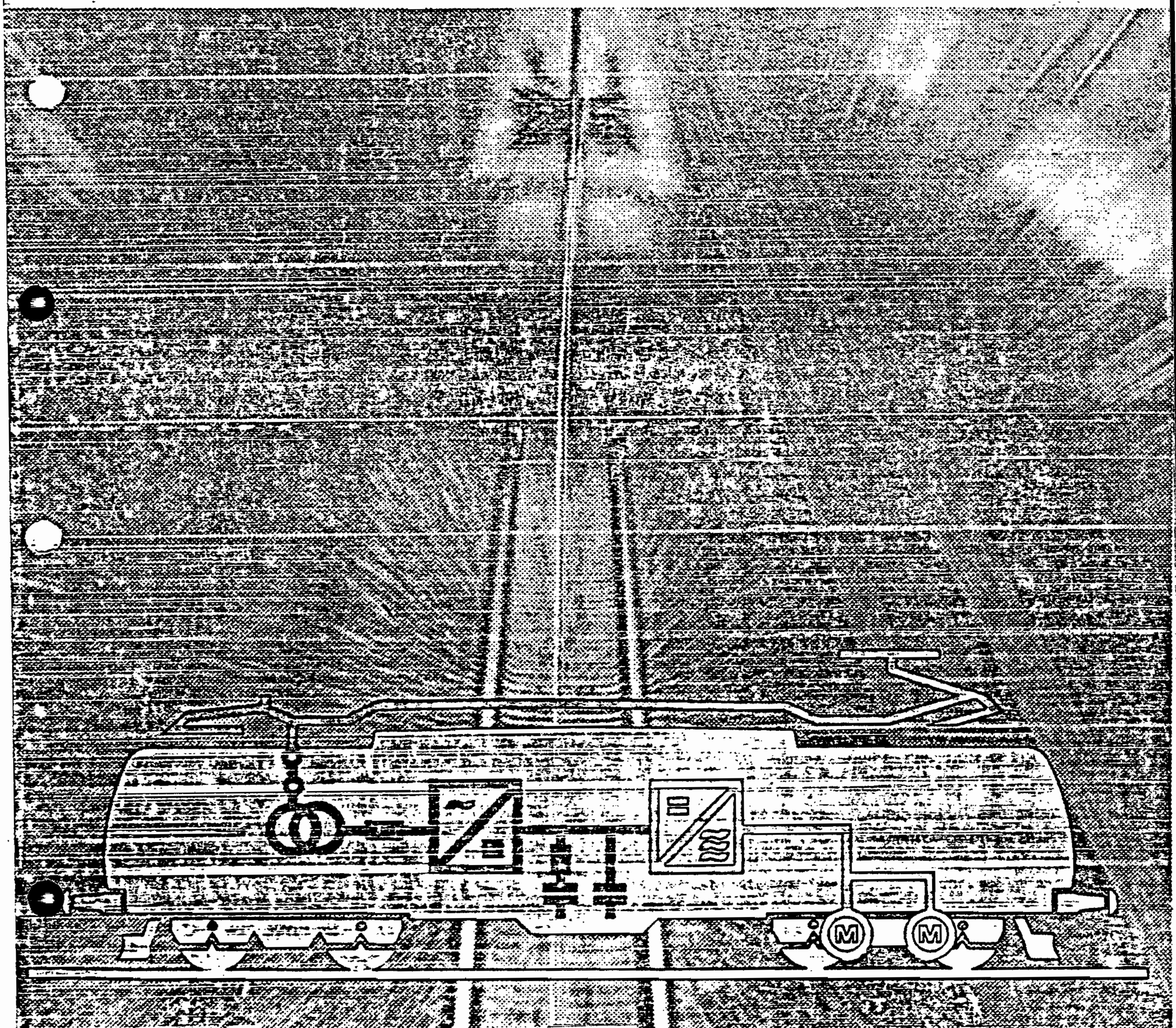
Vierquadrantensteller — eine netzfreundliche Einspeisung für Triebfahrzeuge mit Drehstromantrieb

von Helmut Kehrmann, Wolfgang Lienau,
und Reiner Nill, Mannheim

ALL-ROUND CONTROL ELEMENT -- A LOW NETWORK STRESS SUPPLY FOR RAIL MOTOR CARS WITH THREE PHASE DRIVE

Sonderdruck aus
„Elektrische Bahnen“
45. Jahrgang, Heft 6/1974

Druckschrift-Bestell.-Nr.
E GVK 40076 D



1. Introduction

The heavy increase in traffic in recent years, and long with it the concern over the ever more pronounced pollution of the environment, have led to the desire for more extensive development of routed traffic. In addition to expansion of short-distance public transportation and the creation of traffic systems which may be of entirely new kinds, and fundamental goal is that of increasing the speed and efficiency of long-distance rail traffic [1], [2], [3], [4]. This necessarily involves an increase in propulsion efficiency. Requirements such as the following are set especially for the propulsion vehicles provided for this application:

Low rail stress

Increase in the speed of travel is accompanied by increase in the stress on the rail. If maintenance and investment costs for the superstructure are to increase greatly, the requirement must be set of decrease in wheel set and bogie weight [5].

Low network stress

Increase in propulsion efficiency involves increase both in the cost of energy itself and to a great extent also in investment costs of energy production and distribution. Special effort is thus exerted to keep the apparent power requirement as low as possible [6]. In addition, signal circuits and telecommunications should not be affected by current distortions such as may occur with static converter drives in particular [7].

Low operational stress

Motors must be employed which operate free of wear and perform a variety of functions.

The requirement for low rail and operational stress is especially well satisfied by means of a drive with light, low-maintenance three-phase asynchronous motors [8]. To permit inifinitely variable control of propulsion over the entire traction-speed range, the asynchronous motor must be supplied from a source of three-phase voltage, preferably a self-commutated inverted converter, the voltage and frequency of which can be adjusted from zero to a maximum value.

Such static converter three-phase drives have already been produced for certain vehicle prototypes [9], [10]. The static converter is in this case an intermittent converter operated by a direct voltage intermediate circuit. Non-intermittent power from the generator or the direct voltage trolley is available with such vehicles.

The additional problem of energy storage arises if the advantageous three-phase drive is also to be employed with vehicles fed from the alternating voltage trolley. It is true that the inverted converter drive takes approximately constant power from the intermediate circuit, but the alternating voltage network can provide only power pulsating at twice the frequency of the network. Hence it it is necessary to find the most advantageous possible combination of static converter and filter circuit as the feed circuit.

The following requirements are to be set for the feed circuit:

(a) Provision of a constant direct voltage with slight higher harmonics. The ripple factor

$$r = \frac{u_{max} - u_{min}}{u_{max} + u_{min}} \qquad (1)$$

must be as small as possible.

(b) Insofar as possible, only active power is to be taken from the alternating voltage network, that is, the power factor

$$\lambda = \frac{P}{S} = g \cdot \cos\varphi \qquad (2)$$

must be as large as possible. (P = active power, S = apparent power, g = fundamental oscillation value, $\cos\varphi$ = network displacement factor, according to DIN [German Industry Standard] 40110.)

(c) The outlay for the plant in terms of weight, volume, and costs should be as small as possible.

The plant must, of course, be dependable and safe in operation and must require little maintenance.

Items (b) and (c) of the requirements also apply to the feed circuits of mixed current vehicles. Well smoothed direct current along with variable inverse motor voltage is naturally required for these vehicles, and at the same time a constant direct voltage which is as smooth as possible must be generated.

The following versions of static converters are employed, among other things, for mixed current vehicles:

1. Two bridge rectifiers with unbalanced divided control, ones whose alternating current terminals are connected to separate secondary transformer windings and are connected in series on the direct current side, and which are actuated consecutively in time [11].

2. Multiple remote control with a static converter economy circuit, in which one of the bridge rectifiers is provided with additional controllable branches connected to intermediate taps of the transformer winding [12].

3. Sectional control with bridge rectifiers with unbalanced divided control, ones whose controllable branches have a quenching device; the firing and ignition times are selected so that fundamental oscillation displacement factor cos φ = 1 or is capacitive [13].

The same static converter versions may be employed in the feed circuit of inverted converter railcars if a transverse capacitance is added to the longitudinal choke. One of the static converters connected in series on the direct current side may in this case also be designed as a diode rectifier [14].

The direct voltage intermediate circuit may, however, also be fed by way of and intermittent current converter. This solution is equivalent to the others from the viewpoint of weight and volume, and is characterized by lower network stress even with the filter elements. A concise presentation of it was given in a discussion paper presented at the session in Graz in 1972; it is described in greater detail in what follows.

2. Principle

The fundamental principle of this feed circuit is to be elucidated with the aid of Figure 1 [15], [16], [17], [18]. An inductance L is connected beyond the alternating voltage input, such as the secondary terminal of the transformer. It is followed by a transverse branch with a quick-break switch S and an uncontrolled rectifier on the direct voltage side of which are a trap circuit

L_2, C_2 tuned to the second upper harmonic of the network frequency and tank capacitor C. Network current i_N and network voltage u_N are required to be in phase. To simplify clarification of the physical processes, it is assumed that:

1. Inductance L of the network choke is negligibly small.
2. Timing frequency f_T of switch S is very high.

A current i_M flows into the rectifier. This current results from modulation of the network current, the input circuit being shortcircuited recurrently by switch S by way of network choke L (Figure 2). The variation in current i_M is as follows:

$$i_M = i_N \cdot \sin\omega_N t \cdot |\sin\omega_N t| = \begin{Bmatrix} +i_N \cdot \sin^2\omega_N t & \text{für} & i_N > 0 \\ -i_N \cdot \sin^2\omega_N t & \text{für} & i_N < 0 \end{Bmatrix}. \qquad (3)$$

(3)

The rectifier allows only the same polarities for its input current i_M and its input voltage u_S. Modulated current i_M is in phase with i_N.

In order for the input condition for the rectifier to be satisfied, and at the same time for the requirement of identity of phase of i_N and u_N to be met, condition $1 (L \rightarrow 0)$ must be fulfilled. i_N, u_N, i_M, and u_S are then in phase, the negative half-wave of i_M is reversed by the rectifier, and output current i varies as follows:

$$i = |i_M| = i_N \cdot \sin^2\omega_N t = \frac{i_N}{2}(1 - \cos 2\omega_N t) = I - I\cos 2\omega_N t\,, \qquad (4)$$

Current i is thus made up of a direct component I and an alternating component with double the the network frequency. This second higher harmonic flows through trap circuit L_2, C_2. There remains the direct component I, which corresponds to load current I_g of the direct voltage circuit.

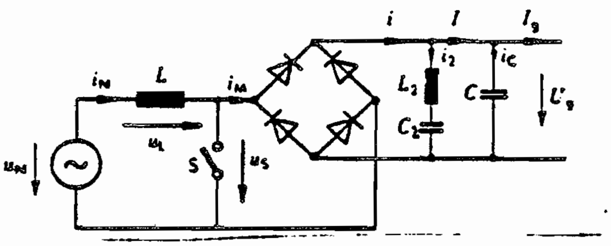


Figure 1. Basic circuit diagram.

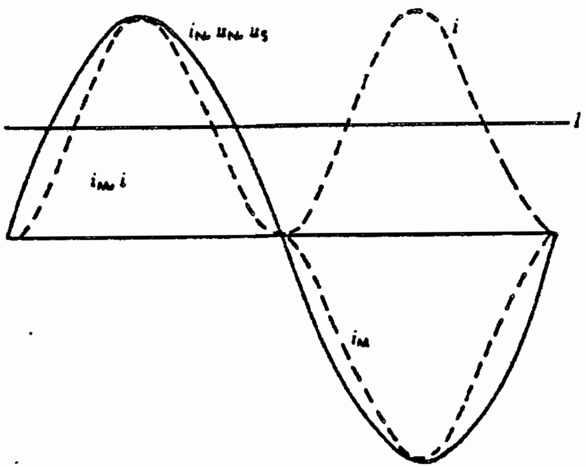


Figure 2. Curves for L = 0 and f_T

Condition 1(L 0) is to be done away with in the next step. The network choke must possess a specific inductivity so that the network voltage will not increase too sharply when switch S closes.

The voltage drop on the choke causes a shift in the phase of voltage u_S at the rectifier input relative to that of the network current and network voltage, through angle . The relationships are illustrated in Figure 3. The timing is nevertheless shifted in phase so that it will be possible to obtain the desired variation for i, consisting of a direct component and the second upper harmonic:

$$i_M = i_N \cdot \sin \omega_N t \cdot |\sin(\omega_N t - \varphi)| . \qquad (5)$$

Since, however, the rectifier allows only input voltage and input current having the same polarities, the "negative current crests" of i cannot flow through regions I and III. Hence the desired variation in i is not achieved by use of the circuit illustrated in Figure 1, which represents a two-quadrant control element.

Transition must thus be made to an all-round (four-quadrant) control element (4 q-S). It is obtained from the two-quadrant control element by incorporating an additional valve branch permitting a negative current to flow in regions I and III.

The need for the additional valve branch may also be explained as follows: the network inductance absorbs apparent power, but must not take it from the alternating voltage network, since according to the requirement i_N and u_N must be in phase. Hence the apparent power must be supplied from the direct current side, and the static converter must be able to provide feedback. Hence use is made of a 4 q-S, which can perform the three functions of "rectification," "timing," and "feedback."

The basic circuit diagram of such a 4 q-S is given in Figure 4. The timing frequency must be limited because of the properties of the structural elements, such thyristor release time and switching losses. The requirement $2(f_T \to \infty)$ must consequently be eliminated.

Output current i and input voltage u_S of the control element then consist of a sequence of units as shown in Figures 5 and 6. As a result of the timing, high-frequency components are additionally superimposed on network current i_N and direct voltage U_g.

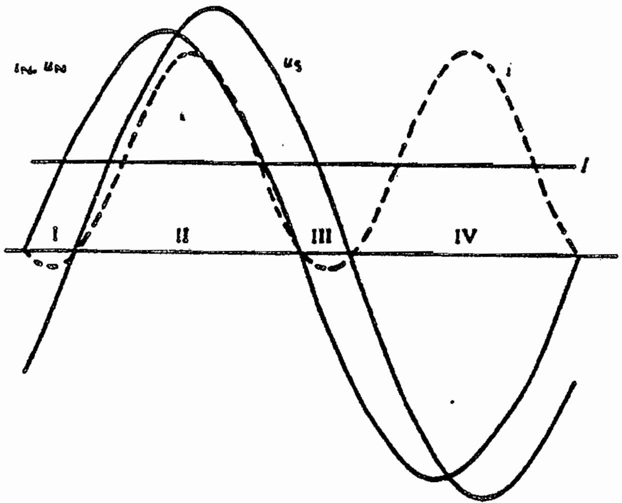


Bild 3. Verläufe bei $L \neq 0$ und $f_T \to \infty$.

Figure 3. Curves for $L \neq 0$ and f_T

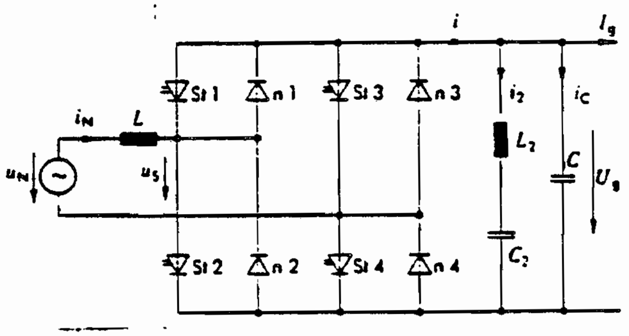
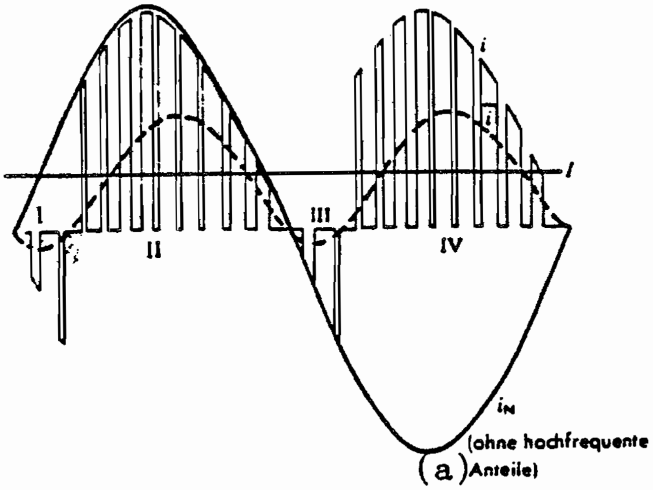


Figure 4. Basic circuit diagram of all-round control element.



lild 5. Stromverläufe bei $L \neq 0$ und $f_T \neq$ ::.

Figure 5. Current curves for $L \neq 0$ and $f_T \neq$
(a) (without high-frequency components).

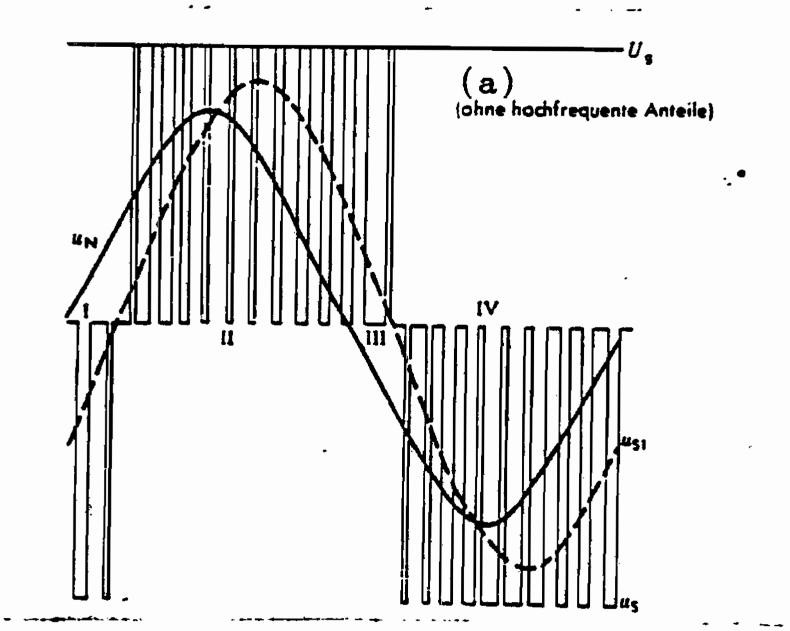


Figure 6. Voltage curves for L 0 and f_T
(a) (without high-frequency components).

3. Control

A block diagram of the 4 q-S, its filter elements, and the control system imposed is shown in Figure 7. The 4 q-S is represented by the functions "timing" and "polarity assignment," the latter including both the function "rectification" and the function "feedback."

The import of "timing" is that either the network current is advanced to the direct voltage circuit ($i_M = i_N$) and the direct voltage is connected to the alternating voltage side ($u_S = \quad U_g$) or the netowrk current is shortcircuited by way of the control element ($i_M = 0$) and the voltage is shortcircuited at the control element ($u_S = 0$).

The import of "polarity assignment" is that, depending on the valve branch which conducts, the positive or negative network current is conducted through to the direct voltage network ($i = + i_N$ or $- i_N$) or the positive or negative direct voltage is connected to the alternating voltage side ($u_S = -U_g$ or $+U_g$). It is to be seen that the voltage, u_L, on the choke assumes three different values, as a function of the 4 q-S control:

$$u_L = \begin{Bmatrix} u_N \\ u_N - U_g \\ u_N + U_g \end{Bmatrix}. \qquad (6)$$

However, the choke voltage generates a specific network current curve steepness. The network current curve consists of segments of varying steepness, the control element assigning the commutation points.

There are various methods of determining these commutation points. An especially clear idea is provided by two-point control. A theoretical phase value sin ${}_N$t synchronous with the network voltage is generated by way of a digital switch (adjustment to cos $\varphi = 1$) and is multiplied by a theoretical amplitude value $i_{N_{soll}}$ (adjustment to $U_g = U_{g\ soll}$ = const.). The difference between the theoretical and the actual current values is then evaluated by two two-point control elements with different hysteresis values, and is converted to control signals for the 4 q-S. This is illustrated in detail by Figure 8 and 9.

The output signal of the control element with the smaller hysteresis value denotes <u>more current -- less current</u>, while the control element with the larger hysteresis value effects inversion of the range, that is, determines whether apparent power from the intermediate circuit is to be fed back or not. In region I, at the beginning of the first half-period of the network current, the shortcircuit causes only a gentle rise in current by way of the network choke ($u_L = u_N$). Switch is made to the direct phase sequence voltage component ($u_L = u_N + U_g$) so that it will be possible to trace the theoretical current value in this region as well. This corresponds to feedback of apparent power from the intermediate circuit. In region II, on the other hand, the shortcircuit ($u_L = u_N$) causes a steep rise in current because of the network voltage, which has become larger in the meantime. Reduction of the current value is accomplished by switching to inverse voltage ($u_L = u_N - U_g$) this corresponding to feed into the intermediate circuit. Intermediate circuit voltage U_g should be higher than the network voltage peak value, so that downward regulation of the current, and thus tracing of the theoretical curve, in the peak value area.

It is to be seen from Figures 7 and 9 that the network choke may be charged ($u_L = u_N$) both by way of the upper branches of the valve (for $i_N > 0$ by way of n1, St3) and by way of the lower branches (for $i_N > 0$ by way of St2, n4). This provides the possibility of operation of operation of the branches of the static converter at the same average timing frequency, so that double the timing frequency is obtained as a result in the network current.

Just as in the case of the inverted pulse converter on the motor side, the upper and the lower halves of the valve branch always conduct current alternately. Hence the same structural groups employed for the three-phase inverted converter may be used for the two-phase 4 q-S.

Lastly, it is to be pointed out that either capacitive displacement of the network current may be effected, as desired, by means of the theoretical phase value assignment. The theoretical current value may also be assigned in such a way that the 4 q-S feeds back into the alternating current network or to an additional retarding resistor and thus performs the function of the electric brake together with the inverted converter drive operating as a generator.

4. Dimensioning Principles

Certain rules governing the dimensioning of control elements and filter elements are to be discussed in what follows. The currents and voltages on the network side and in the intermediate circuit may be divided into components caused by the network voltage and ones originating in the timing of the control element.

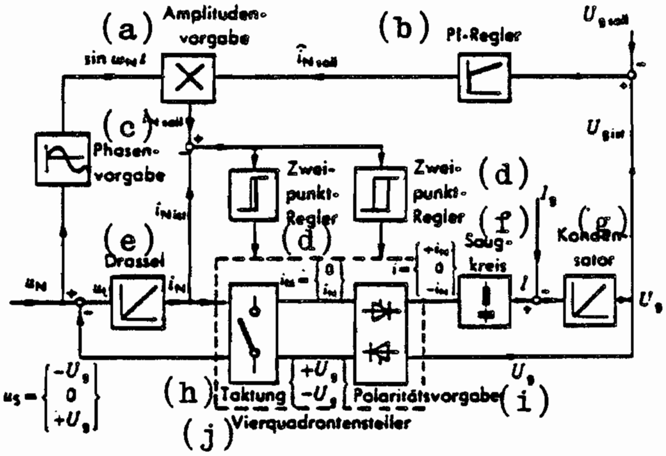


Bild 7. Blockschaltplan des Vierquadrantenstellers.

Figure 7. Block diagram of all-round control element. (a) amplitude assignment. (b) Pl regulator. (c) Phase assignment. (d) two-point regulator. (e) choke. (f) trap circuit. (g) capacitor. (h) Timing. (i) polarity assignment. (j) all-round control element.

Only the first harmonic components generated by the network voltage (subscript 1) are to be considered at the outset. Figure 10 represents a vector diagram of the alternating voltage side. The following relations may be derived directly from it:

power-supply voltage: $u_N = \hat{u}_N \cdot \sin \omega_N \cdot t;$

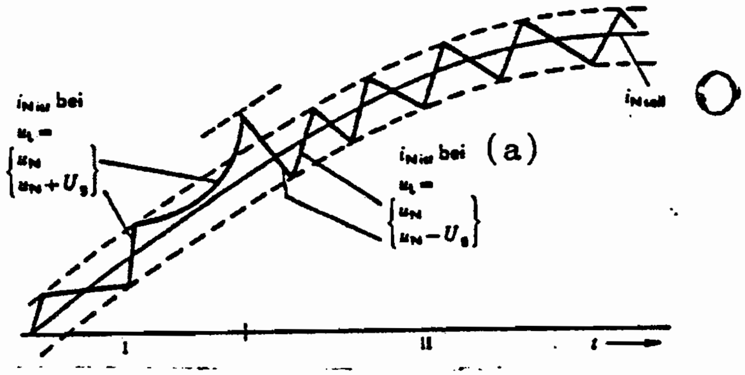


Figure 8. Network current curve for the all-round control element. (a) with.

	$u_L =$							
	u_N+U_g	u_N		u_N-U_g	u_N-U_g	u_N		u_N+U_g
St 1					▮	▮		
n 1			▮	▮				
St 2	▮	▮						
n 2							▮	▮
St 3	▮		▮					
n 3						▮		▮
St 4					▮		▮	
n 4		▮		▮				
	$i_N>0$				$i_N<0$			

Figure 9. Valve control table.

Network current:

$$i_{N1} = \hat{i}_{N1} \cdot \sin \omega_N \cdot t \,. \qquad (8)$$

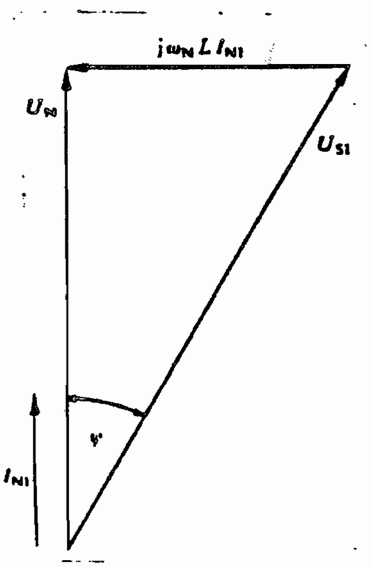


Figure 10. Vector diagram.

The voltage first harmonic u_{S1} is necessary on the alternating current terminals of the control element in order for this network current to be able to flow.

$$u_{S1} = \hat{u}_{S1}\cdot\sin(\omega_N\cdot t-\psi) \qquad (9) \qquad (9)$$

$$\hat{u}_{S1} = \frac{\hat{u}_N}{\cos\psi} \qquad (10) \qquad (10)$$

$$\hat{i}_{N1} = \frac{\hat{u}_N}{\omega_N\cdot L}\cdot\tan\psi \qquad (11) \qquad (11)$$

The control element input voltage is obtained as described through interruption of the direct voltage. The relation

$$u_{S1} = U_g\cdot k\cdot\sin(\omega_N\cdot t-\psi), \qquad (12)$$

in which k is the maximum degree of modulation.

Since the control element itself has no energy storage other than the commutation elements, the output at its alternating current terminals and direct current terminals must necessarily be the same at all times.

$$i_{N1} \cdot u_{S1} = U_s \cdot i. \qquad (13) \qquad\qquad (13)$$

i is the output current of the control elements without the higher harmonics caused by the timing.

(14)

$$i = i_{N1} \cdot \hat{k} \cdot \sin(\omega_N \cdot t - \psi) \qquad (14) \qquad\qquad (15)$$

with

$$i = I - i_2 \cdot \sin\left(2\omega_N \cdot t + \frac{\pi}{2} - \psi\right) \qquad (15)$$

$$I = \frac{\hat{k} \cdot \hat{u}_N \cdot \sin\psi}{2 \cdot \omega_N \cdot L} \qquad (16)$$

(16)

$$i_2 = \frac{\hat{k} \cdot \hat{u}_N \cdot \tan\psi}{2 \cdot \omega_N \cdot L} \qquad (17)$$

(17)

Higher harmonics originating in the finite timing frequency of the control element are superimposed on these first harmonic values.

The sum of the network current higher harmonics forms an approximately triangular pattern, the amplitude and the time of rise or drop varying from one timing period to another as a function of the network voltage behavior. The maximum amplitude of the higher harmonic occurs when the duration of operation and duration of interruption of operation of the control element are of equal length. Since the current amplitude in a choke is proportional to the adjacent voltage time surface and inversely proportional to the inductance, the following relation is obtained:

$$i_{NT} \sim \frac{U_s}{f_T \cdot L}. \qquad (18)$$

in which i_{NT} is the maximum amplitude of the network current higher harmonic and f_T the effective timing frequency of the control element.

The power factor of the network power is additionally determined only by the first harmonic content of the current

$$g=\frac{I_{N1}}{I_N}=\lambda \quad \text{bei} \quad \cos\varphi=1 \tag{19}$$

The power factor decreases with increase in the amplitude of the higher harmonics.

The higher harmonics of control element output current i caused by the timing flow through tank capacitor C, since the trap circuit represents high resistance for frequencies which differ widely from the resonance frequency of the trap circuit. The tank capacitor value is determined from the maximum current time area of this higher harmonic current and the permissible voltage ripple factor r of the intermediate circuit voltage:

$$C=\frac{\int i_c\,dt}{\Delta U_g}. \tag{20}$$

The dependence

$$C\sim\frac{i_N\cdot \bar{k}}{r\cdot U_g\cdot f_T} \tag{21}$$

may be formulated for this case.

As is known, the dimensioning of a self-commutating static converter is determined chiefly by four parameters:

-- maximum static and dynamic terminal voltage;

-- maximum current to be commutated;

-- average timing frequency and minimum time between two commutations (commutation dead time);

-- the load current value or the losses caused by this current.

The physical size of a choke is determined by the inductance, permanent current, and maximum current, and that of a capacitor by the capacitance, maximum voltage, and recharging losses. The dependence of the total expenditure on the choice of parameters can be determined from these relationships. The choice made of the pair of values represented by the control element timing frequency and the network inductance is of particular importance.

Let it be assumed that the requirement has been set for a specific current ripple factor and a specific power factor. The network inductance can be reduced with increase in the timing frequency of the control element. The angle between the network voltage and the control element voltage is consequently also reduced. With the intermediate circuit voltage the same, the voltage of the transformer secondary windings may be increased and the input alternating current reduced. Hence the physical size of the network choke is reduced not only in proportion to its inductance, but also by reduction of the current.

However, smaller filter elements in the intermediate circuit are also obtained with increase in the timing frequency. Both the trap circuit current and the necessary capacitance of the tank capacitor undergo linear decrease with decrease in the network current, and the capacitance in addition with decrease in the timing frequency. It is true that the static converter must now conduct a lower current, but the losses increase with increase in the timing frequency. In addition, the degree of modulation k decreases, since the available voltage time is reduced by the commutation dead time. Hence the circuit expense at first decreases with increase in the timing frequency, but then this expense and the losses in the control element increase out of proportion at relatively high timing frequencies. Even higher effective timing frequencies can then be achieved by means of combinations of several control elements and phase shifted timing.

The voltage tolerances of the contact wire also exert a heavy influence on the dimensioning of static converters and filters. The transformation ratio of the transformer must be established for the maximum network voltage and the minimum intermediate circuit voltage at which sinusoidal network current is still required. However, the highest network current, and thus the greatest stress on filter elements and static converter, occur at the lowest network voltage at which full power must still be transmitted.

5. Test Results

The theoretical considerations were subjected to practical verification by means of a test stand in the laboratory. The 4 q-S was fed by way of a locomotive transformer from the 16-2/3 network of the German Bundesbahn. Following are technical data on the test stand:

Network voltage	U_N = 590 V (+20%, -30%)
Intermediate circuit direct voltage	U_g = 1200 V
Intermediate circuit power	P_{gmax} = 240 kW

The static converter component of the 4 q-S consisted of two phases of the inverted converter circuit free of blocking voltage [9]. The tests of the 4 q-S covered the behavior of the latter under load from ohmic resistances and an inverted converter drive. The pertinent current and voltage curves, transformer secondary current and voltage, control element input voltage, intermediate circuit voltage, and trap circuit current are shown in Figure 11. The values were recorded with the 4 q-S under the maximum load.

The following test results demonstrate how well the 4 q-S satisfies the requirements set for it: Under full load the network current pulsation w was 20% (superimposition factor according to DIN 40110), the ripple factor r of the intermediate circuit voltage 5%, and the power factor 0.98. Power factor is shown in Figure 12 plotted against relative intermediate circuit power P_g/P_{max}. The practical results demonstrate very good agreement with the theoretical values and analog computer simulations. The 4 q-S has proved its ability to function even under abrupt increases in load and during network voltage interruptions (disconnection of the current collectors).

Solution of the network protection problem for the 4 q-S is facilitated by the high inductance of the energy supply. (The transformer stray reactance and the choke reactance yielded a relative shortcircuit voltage of 30% on the basis of the test data.) Excess network voltages can be absorbed by the network choke without danger to the 4 q-S, without substantial increase in the intermediate circuit voltage of significance in dimensioning of the control element components. The rise and amplitude of the shortcircuit current possible in the event of failure are effectively limited.

6. Prospects

Theoretical study, and now practical study as well, are being made of expanded 4 q-S circuits and pertinent controls. An especially promising version is one in which two 4 q-S are connected in parallel on the network side, each by way of the secondary winding of a transformer, and operate with a common intermediate circuit. Control is accomplished by means of phase-shifted timing of the two 4 q-S. As a result, the higher harmonics of the network currents are shifted 180° electrically relative to each other on the secondary side, and thus are largely cancelled out on the primary side through summation.

Figure 13 illustrates the result of simulation by an analog computer. A power factor of 0.999 is obtained under full load for the primary summary current, along with a power factor of 0.98 for both secondary currents.

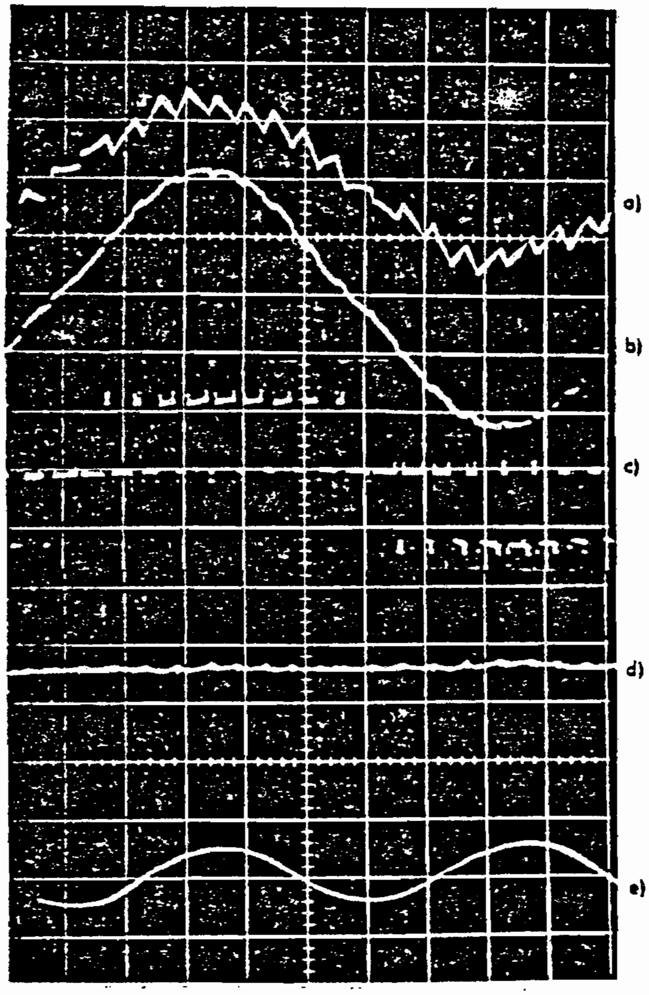


Figure 11.

(a) Network current i_N
(b) Network voltage u_N
(c) Control element input voltage u_S
(d) Intermediate circuit voltage U_g
(e) Trap circuit current i_2

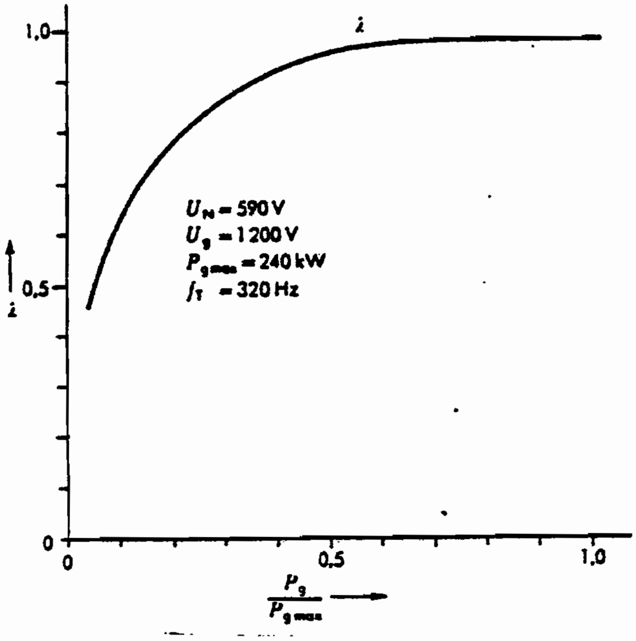


Figure 12. Power factor as a function of relative intermediate circuit power.

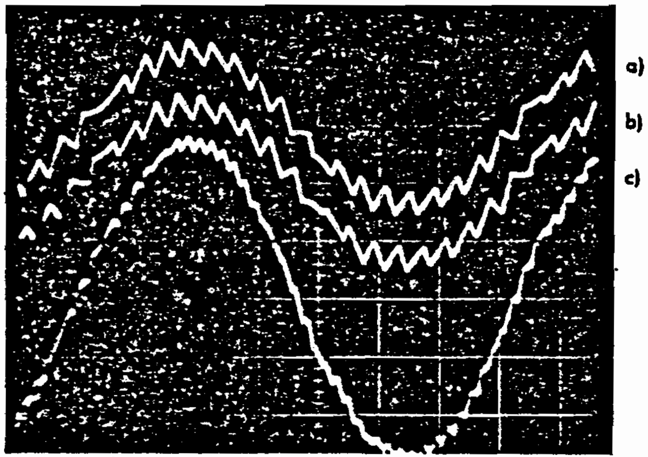


Figure 13. Phase shifted timing.
(a) and (b) Network currents on secondary side.
(c) summary current on primary side.

7. Summary

An effort is made to apply the advantageous three-phase drive also to propulsion vehicles supplied from an alternating voltage contact wire. The propulsion inverted converters in this case operate with a direct voltage intermediate circuit. A description is given of an intermittent current converter circuit (all-round control element) which can supply this direct voltage network from a single-phase alternating voltage network with virtually no apparent power. Measurements on a test stand yielded a power factor of 0.98. In addition, the power factor can be further improved by connection in parallel and phase shifted timing of two all-round control elements.

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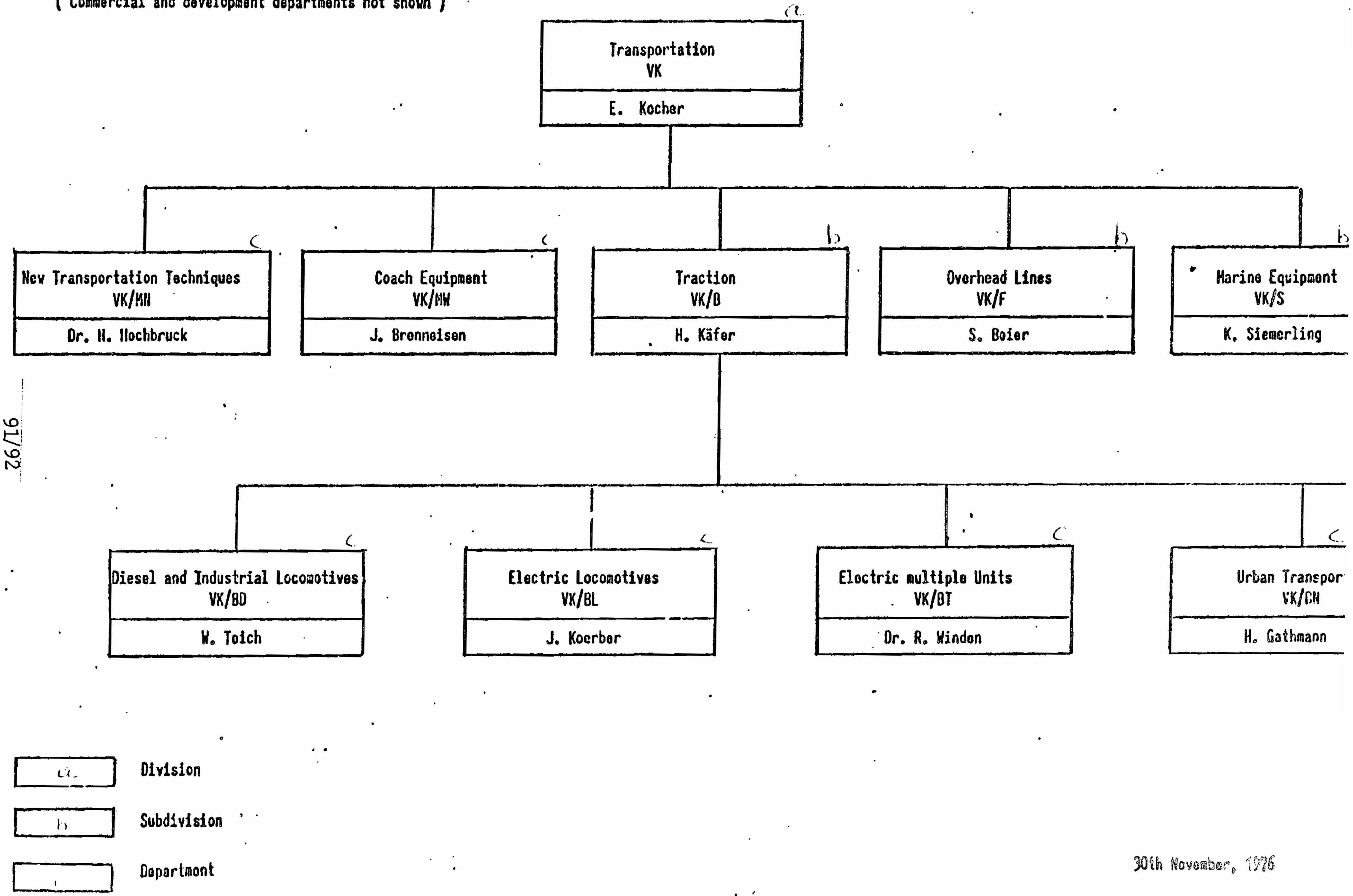
ATTACHMENT C

R A Uh

B B C Mannheim - Transportation Division

Simplified organisation chart

(Commercial and development departments not shown)



30th November, 1976

ATTACHMENT D

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BBC
BROWN BOVERI

Three-phase motors for diesel and electric traction

by Dipl. Ing. J. Körber and Obering. W. Teich

Brochure Order No.
D VK 50675 E

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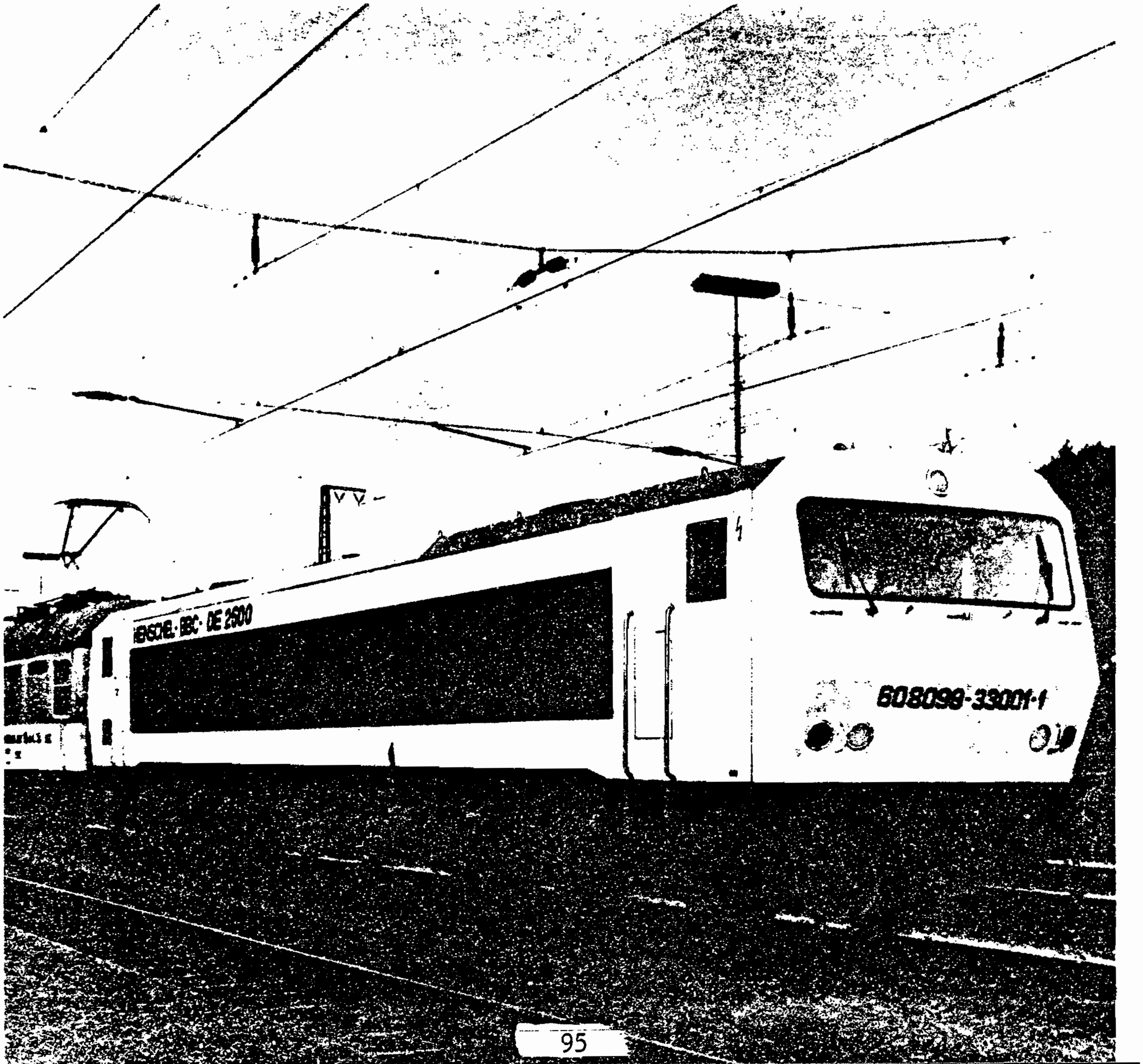


Three-phase motors for diesel and electric traction

Dipl-Ing J Körber and Obering W Teich
Brown Boveri & Cie AG, Mannheim

THE ATTRACTIONS of using the asynchronous three-phase induction motor for traction were recognised at an early date, but could not gain ground due to the lack of adequate control equipment. The squirrel-cage traction motor—so called because of the extreme simplicity of its construction and the absence of any external electrical connection to the rotating armature—presented no problems, but control equipment that could vary the frequency as well as the voltage presented insurmountable difficulties until the coming of semi-conductors. Three-phase electric traction systems requiring twin catenaries, were soon replaced by dc or single-phase ac because of their complexity.

Now semiconductors have made it a relatively simple matter to convert any source of electrical energy into a three-phase supply, the frequency and voltage of which can be varied almost instantaneously. The problems of developing such equipment for economic and reliable operation remain considerable, however, and only a limited number of attempts have been made.

Brown Boveri of Mannheim teamed up with Henschel to produce in 1971 the first of three prototype diesel-electric locomotives of 2 500 hp with ac/dc/ac transmissions. They were described in the May 1971 issue of RAILWAY GAZETTE, and two of them have been in regular service with the German Federal Railway (DB) for some time.

More recently, locomotive No. 202 002 has been modified for straight-electric drive. The diesel engine and alternator were replaced by iron ballast weights, but the high voltage equipment is carried on a test coach which is permanently coupled to the locomotive. In this form, No. 202 002 went into revenue service on the DB in October 1974, and several thousand kilometres have been accumulated hauling, for example, 2 000 tonne freight trains.

Advantages

Asynchronous induction motors offer a number of important advantages over the traditional commutator motor:

- more space is available for the stator laminations within a given motor volume;
- the motor can be operated at a higher voltage;
- rotational speed is not limi[illegible]y the commutator;
- there are no sliprings, commutator or brushgear to maintain;
- changeover from traction to braking without the use of contactors;
- very steep natural characteristics prevent wheel slip;
- a small light motor allows very simple bogie design.

These advantages are so important that the use of three-phase traction motors certainly represents a significant step forward in the field of diesel and electric traction.

The traction motors are fed from intermediate dc busbars through inverters. Power is supplied either by a diesel engine driving an alternator, or direct from the overhead contact wire.

The lightweight traction motors and many other features, especially the favourable tractive effort/speed characteristics which automatically limit wheel-slip and ensure (at maximum speed) a tractive effort twice as high as that of conventional locomotives of equal maximum power, are ideal for straight-electric locomotives with their high concentration of power.

The three DE 2500 diesel locom[illegible]es were a speculative development by BBC and Henschel, but it was at the instigation of the DB that investigations were carried out to see how this technique could best be adapted to the German

After four years of development, solid-state power conversion devices have proved a satisfactory and reliable way of gaining the benefits of asynchronous three-phase induction motors for traction; these include better adhesion characteristics as well as a lighter and more robust motor needing less maintenance. Now one of three diesel-electric prototypes is in service in straight electric form, proving the versatility of this form of drive

15 kV 16⅔ Hz traction power supply. Dependence on an external supply network with its voltage fluctuations and interruptions in supply imposes additional demands as regards protection and dynamic behaviour of the energy conversion equipment. In view of the results achieved with phase-angle controlled vehicles, it is most important—especially when using an external 16⅔ Hz supply—to pay special attention to the reactive component of the electrical load, and the consequent effects on the supply network.

Test results obtained with Bo-Bo locomotive No. 202 002 during 1974 have therefore proved to be of particular importance.

Diesel experience

The exceptionally light traction motors allow a good design of lightweight bogie to be used, which ensures very good riding characteristics. This applies both to the Bo-Bo and Co-Co versions, the latter being intended for use in countries where light axle-loads are specified. During the course of trial runs, the ride quality up to a speed of 165 km/h was measured. There was no falling off in the ride quality compared with the normal maximum speed of 140 km/h.

Operators have commented favourably on the behaviour of the locomotive as regards wheel-slip. The traction motors are all connected in parallel and are thus electronically coupled, but in a flexible way. All motors, therefore, receive the same supply frequency, and to this extent their speed is predetermined.

If the adhesion for one axle is not sufficient to transmit the torque, the speed of this axle will increase only slightly due to the natural characteristic of the asynchronous motor. During starting, a slipping axle will typically have a rim speed which does not exceed that of the non-slipping wheels by more than 0·4 km/h. Conventional locomotives require automatic devices to correct wheel-slip by reducing the tractive effort, which therefore affects the performance of the locomotive adversely. With three-phase motors all of the available adhesion can be fully utilised.

The three-phase power transmission of the DE 2500 locomotive adapts very flexibly to the output characteristics of the diesel engine. Transmission characteristics are normally selected for minimum fuel consumption.

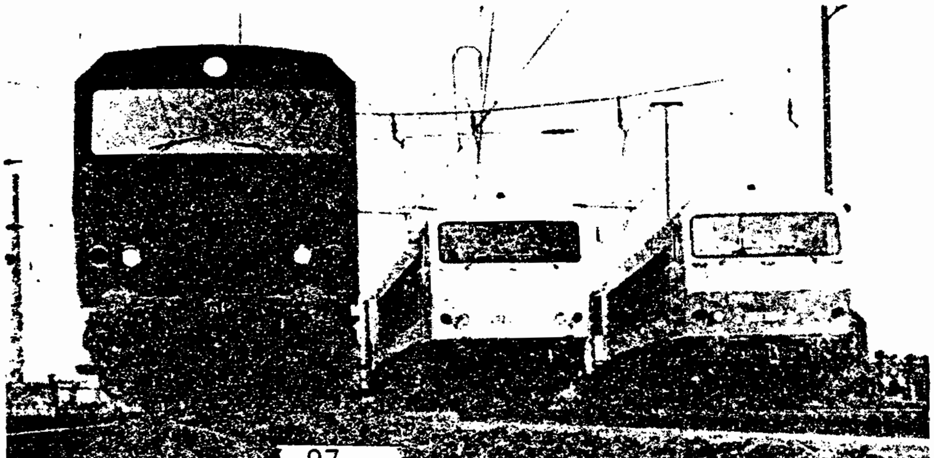
Fuel savings

Savings in fuel are specially significant when the locomotive provides an electric power supply for train heating or air-conditioning. The brake resistor and, in parallel with it, the inverter for power supply to the train are connected to the common dc busbar as shown in Fig. 1.

When dynamic braking is in use, the asynchronous motors supply energy to the dc busbar via the traction inverter. This dc busbar feeds the inverter for power supply to the train, and also into the dynamic brake resistance bank. During braking the electric power supply to the train is thus provided by the traction motors operating as generators rather than by the diesel engine, a kind of regenerative braking. The electric brake is generally preferred by drivers to the air brake.

Starting losses with the three-phase power transmission are low, compared to hydraulic transmissions. Maximum possible tractive effort at standstill is required on engine output of no more than 300 hp. This output covers the losses of the total system. In contrast, diesel-hydraulic transmission requires almost the full diesel engine output for maximum tractive effort at starting.

It is the fuel injection characteristic of the diesel engine that is used as a basis for power regulation, and this



RIGHT: *Henschel and Brown Boveri produced three DE 2500 series diesel-electric locomotives with three-phase induction motors as a speculation in 1971*

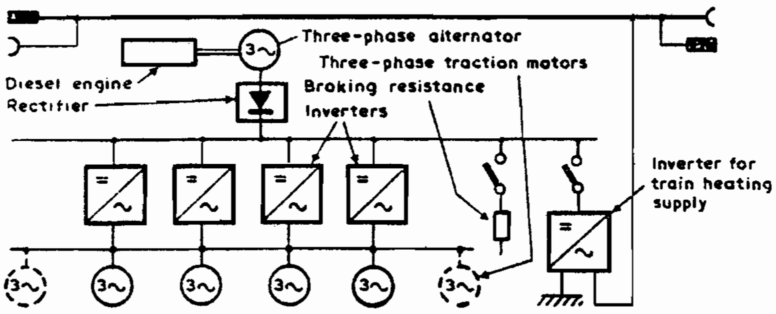


Fig. 1. (LEFT): *Power conversion arrangement for the DE 2500 locomotives; power for train heating is taken from the dc busbars, which are supplied from the traction motors during braking.*

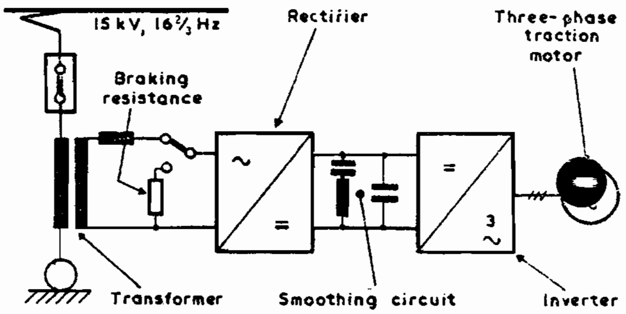


Fig. 2. (RIGHT): *When adapted to take power from the overhead wire, an intermediate dc smoothing circuit is needed between rectifier and inverters*

system will operate satisfactorily in the event of failure of individual cylinders or the use of poor fuel. If, for instance, one cylinder fails, the remaining cylinders will not be used for compensation but their operation is continued with the same fuel injection reference value.

The system also functions satisfactorily when auxiliaries are disconnected, since the amount of power no longer required can be supplied direct to the three-phase power transmission. Experience with these locomotives shows that under all service conditions, the diesel engine is always loaded to its preset reference values.

The tractive effort/speed characteristic of the DE 2500 locomotive permits its use on all types of freight duty. The DB uses them for freight and for fast passenger service, and even duty as shunting locomotives would be possible.

Thanks to the elimination of wearing components, the DB has found that regular inspections can be limited as regards the electrical equipment to checking the oil level in the gearboxes and the alternator and traction motor bearings.

Wheel diameter

The question has often been raised as to whether differences in wheel diameters are acceptable with asynchronous motors.

Wheel diameters of the DE 2500s have been carefully monitored over a long period, and the results show clearly that slight differences in wheel diameter detected immediately after completion of the locomotives had disappeared after they had been in operation for a period of time.

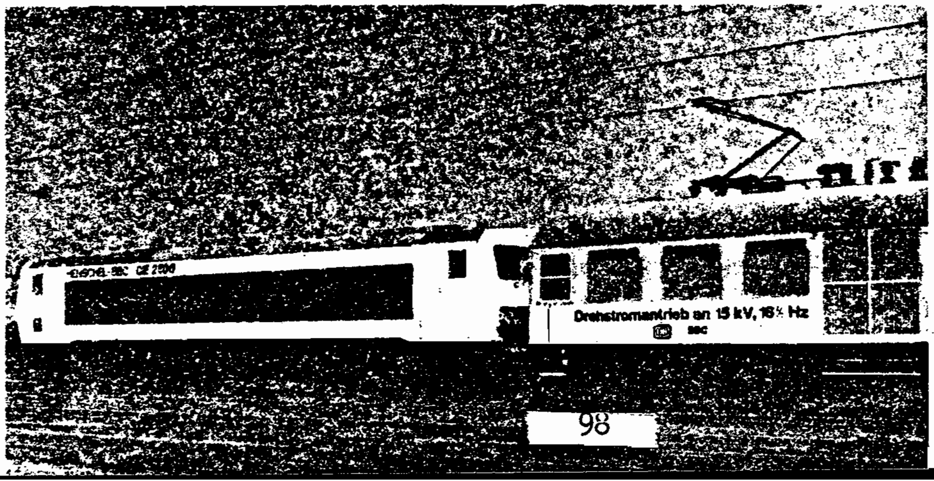
The reason for this lies in the characteristic of the asynchronous motors. The motor which drives the axle with the largest wheel diameter must produce the highest torque because of the common power supply. The wheelset with the largest diameter, therefore, transmits the higher tractive effort, and thus wears out somewhat faster.

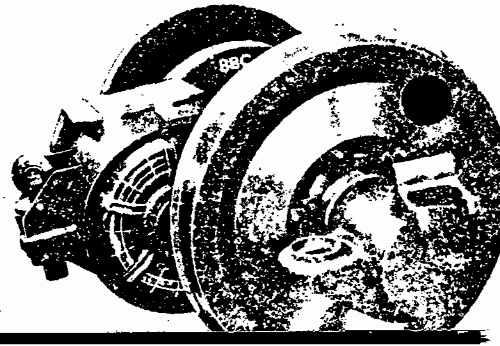
Diesel traction applications

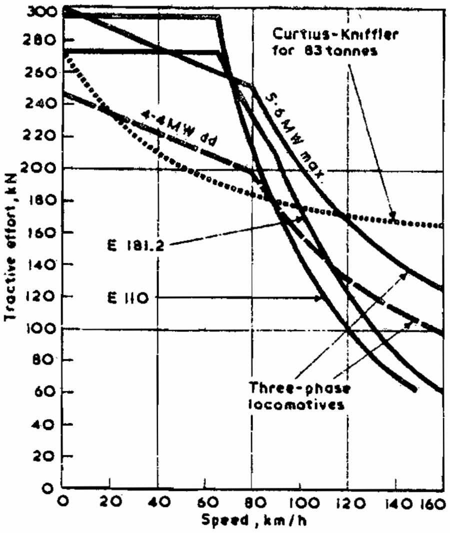
The desire to be able to use locomotives for hauling any type of train is now greater than ever before. The broad requirements for an electric transmission suitable for mixed traffic duties are:

- high continuous tractive effort (freight);
- high maximum speed (passenger);
- gauges from 1 000 mm upwards;
- axleload from 12·5 tonnes upwards;
- modular design with a minimum of individual components;
- adaptability to several kinds of energy supply such as diesel engines, gas turbines, batteries, fuel cells and external supply at the usual dc and ac voltages.

BELOW LEFT: *In recent months No. 202 002 has been operating as a straight electric locomotive permanently coupled to a test-coach carrying electrical equipment.* BELOW RIGHT: *Three-phase motor of type QD 335 S4*







LEFT: *Fig. 3. Tractive effort/speed curves for the experimental three-phase Bo-Bo locomotive compared to standard DB electric locomotives*

Traction motor

At present, two traction motors are available; they differ as to shaft length for gauges from 1 000 mm and from 1 435 mm upwards. The smaller motor is used primarily for locomotives with lower axleloads where the torque requirements are lower, and the Co-Co wheel arrangement may well be adopted.

The axlehung motor for the DE 2500 is designed in such a way that it can be installed with a suspension roller bearing that need not be removed when the motor is exchanged. The motor used for the straight-electric conversion is frame-suspended.

Data for the three motors are listed in Table I (see page 71).

In designing the inverters the modular technique has been used without exception, the smallest module being rated at:

Inverter output	750 kVA
Input voltage	1 500 V dc
Output voltage	0 to 1 250 V RMS
Weight	580 kg

After two such three-phase inverter modules have been assembled back-to-back, a resistor-fan module is placed on top of them. This fan absorbs the energy produced during dynamic braking, as well as cooling the two inverter units and the dynamic braking resistor. Inverter output is increased simply by parallel connection of more modules.

Alternator

The design of the alternator depends on the prime mover used. On the DE 2500 the main alternator is a synchronous generator directly coupled to the diesel engine. The alternator operates at speeds between 600 and 1 500 rev/min according to the diesel engine speed, the frequency varying between 40 and 100 Hz. Since the inverter isolates alternator and traction motors from the electrical viewpoint, the alternator is only rated for an output of 1 800 kVA, corresponding to 2 500 hp. This isolation allows the alternator to carry only a low current at starting even though the traction motors carry their highest current.

This underlines the great difference between the ac/dc/ac traction system and conventional diesel-electric equipment, where the alternator has to supply current direct to the traction motors so its dimensions depend directly on the operating characteristics of the traction motor. With the Brown Boveri system, the size of the alternator depends only on the diesel engine output actually to be converted, so there is no over-dimensioning.

Alternator voltage is regulated by an integral exciter. The output of the auxiliary exciter is rectified within the rotor by diodes and then supplied directly to the main exciter winding

Electric prototype

To try out the BBC three-phase system taking single phase power from the catenary under service conditions, No. 202 002 was coupled to a driving trailer belonging to the DB. In addition to the pantograph, this driving trailer carries the high-voltage equipment, the transformer and the intermediate dc circuit including the specially-developed four-quadrant controller (rectifier) which converts single-phase ac to dc. Power is supplied from the driving trailer to the dc intermediate circuit of the locomotive.

The electronic controls on the locomotive have been modified because the with the diesel-electric drive has been dispensed with. The basic circuit diagram (Fig. 2) shows clearly the new constant-voltage intermediate circuit.

The four-quadrant controller ensures that a quasi sine-wave current proportional to the output is taken from the system. It is made up of the same modules as the traction motor inverter, and is controlled by the same circuit. The motor current is completely isolated as regards frequency and phase from the supply current by the intermediate smoothing circuit.

Test results now to hand confirm the accuracy of theoretical investigations, laboratory tests, and measurements. The power factor—the ratio of the active power (kW) converted in the locomotive to the kVA input—is better than with all ac locomotives produced so far. This is of paramount importance for the energy supply of the railway system, and because of the effects on signalling and telecommunications.

Fluctuations of contact wire voltage and interruptions in supply due to loss of contact at the pantograph can be coped with, and electronic control equipment installed as a precautionary measure has proved to be satisfactory. The locomotive was placed in service on October 4 1974 and is now operated daily by the DB.

Some work has been carried out by Brown Boveri on the design of a 15 kV 16⅔ Hz locomotive with asynchronous motors, encouraged not only by experience on the DB but also in Switzerland, where a power car of the Be 4/4 series was converted in 1973.

Besides the remarkably small bogie weight (the weight of the traction motors is approximately half that of conventional motors) it is possible to obtain twice the tractive effort at maximum speed with a slightly smaller total weight (Fig. 3). The motor intended for this locomotive is the one detailed in Table I under 'electric locomotive'.

Thanks to the use of light traction motors, it will become possible to use higher outputs per axle. In the case of three-phase traction, the power which can be transmitted at the axle depends less on the motors than on the power supply system. So long as enough energy can be supplied to the traction motor, the standard gauge and wheel diameters in use today allow the installation of 2 MW per wheelset. This is of particular interest for dc traction systems.

Experience gained in the last four years with the operation of the DE 2500 prototypes—in both diesel and electric form—shows that operational advantages will easily justify higher expenditure on the power electronics needed. ■

Table I. Traction motor data for the narrow and standard/broad gauge versions of the diesel-electric DE 2500, and the electric-powered version

	Diesel locomotive		Electric locomotive
	1 000 mm gauge	1 435 mm gauge	1 435 mm gauge
Type	QD 335 S 4	QD 335 N 4	QD 646 0 4
Continuous rating (kW)	250	375	1 100
Voltage (V)	1 250	1 250	2 200
Number of poles	4	4	4
Maximum speed (rev/min)	3 700	3 700	3 600
Weight (kg)	1 100	1 800	2 300
External diameter (mm)	660	660	900
Shaft length (mm)	857	1 187	1 128

Perfectionnement du système de transmission de courant alternatif triphasé Brown Boveri—les systèmes de transmission faisant appel au courant alternatif triphasé ont été perfectionnés d'une manière systématique au cours de ces dernières années. Ils n'ont eu, jusqu'ici que relativement peu d'applications pratiques en ce qui concerne la traction ferroviarie. A noter toutefois qu'une grande expérience pratique et utile a été acquise avec trois locomotives prototypes en République Fédérale Allemande et cela apporta la confirmation quant aux bonnes caractéristiques de traction qu'a la performance satisfaisante auxquelles on s'attendait. Les systèmes de transmission de courant triphasé ainsi que leurs avantages concommitants tels que moteurs de traction légers, conviennent parfaitement aux locomotives diesel, sans compter qu'ils présentent un potentiel énorme quant à leur dévelopment ultérieur en vue de la traction électrique directe.

Fortschritt bei der Drehstromkraftübertragung—Die Drehstromkraftübertragung für elektrische und dieselelektrische Triebfahrzeuge ist in den letzten Jahren systematisch weiterentwickelt worden und ist heute bei beiden Traktionsarten voll einsetzbar. Die positiven Betriebserfahrungen lassen erkennen, dass die vielen traktionstechnischen und betrieblichen Vorteile einen höheren Aufwand an Leistungselektronik rechtfertigen. Durch den Einsatz von bisher drei Lokomotiven mit Drehstrom-Kraftübertragung konnte viel Betriebserfahrung gewonnen werden, die erkennen lässt, dass mit der jetzt zur Verfügung stehenden Technologie eine wirtschaftliche Betriebsführung bei günstigen Unterhaltungsbedingungen und einem weiten Anwendungsspektrum sowohl für Triebfahrzeuge mit Verbrennungsmaschinen als auch für rein elektrische Triebfahrzeuge zu erwarten ist.

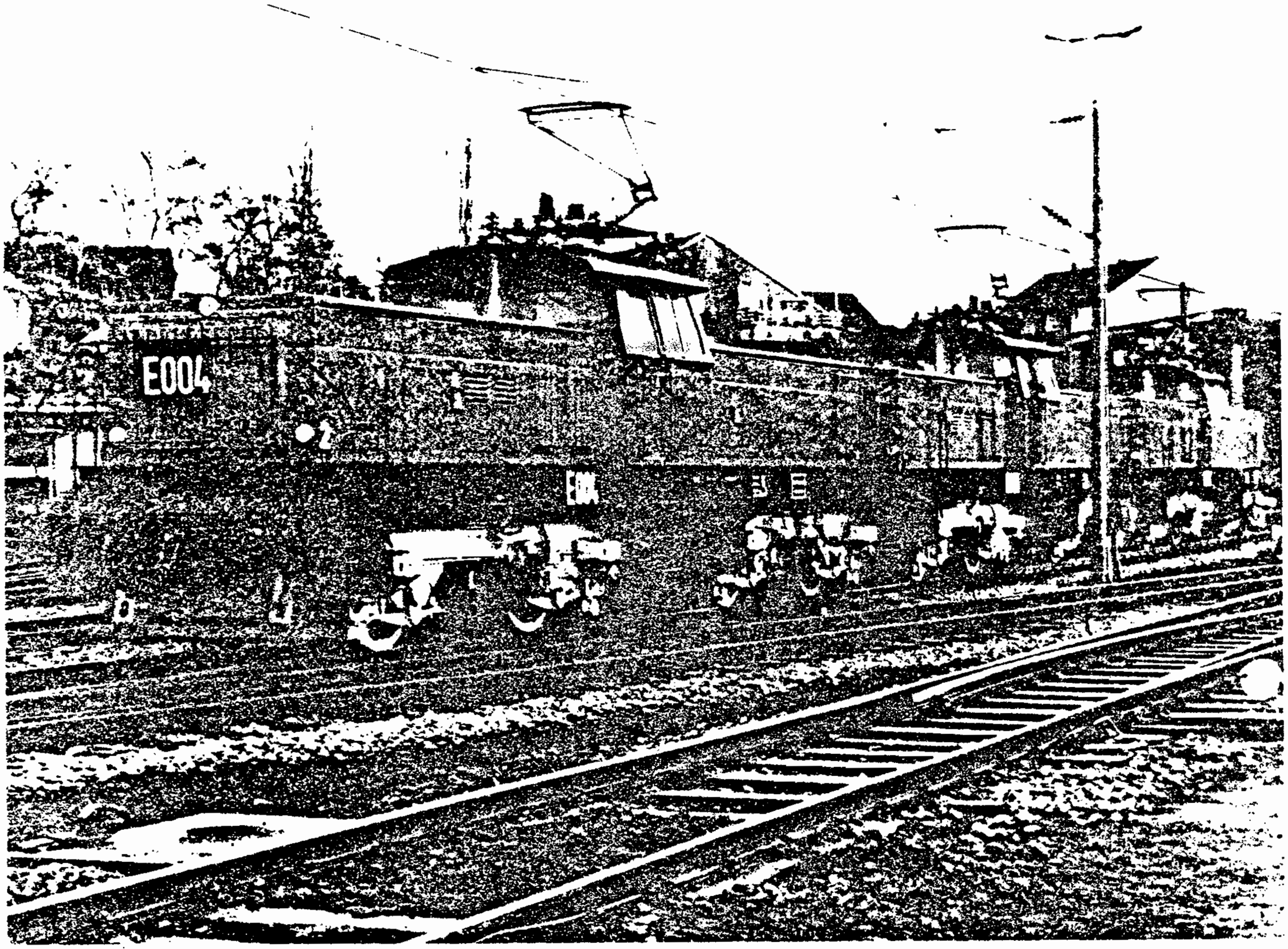
Desarrollo de transmisión con corriente alterna trifásica por parte de Brown Boveri—Los sistemas de transmisión usando corriente alterna trifásica han experimentado un progreso metódico durante los últimos años. Hasta la fecha, la aplicación práctica a las locomotoras ha sido relativamente pequeña. No obstante, se han recopilado muchas experiencias y conocimientos de incalculable valor con tres locomotoras prototipo en la República Federal Alemana, los cuales sirvieron para confirmar el esperado rendimiento satisfactorio y favorables características de tracción. Los sistemas de transmisión trifásicos y sus ventajas concomit[illegible]s, tales como motores ligeros, se ad[illegible]n muy bien a las locomotoras diesel y existe mucha capacidad potencial relacionada con su desarrollo para la tracción eléctrica directa.

ATTACHMENT E

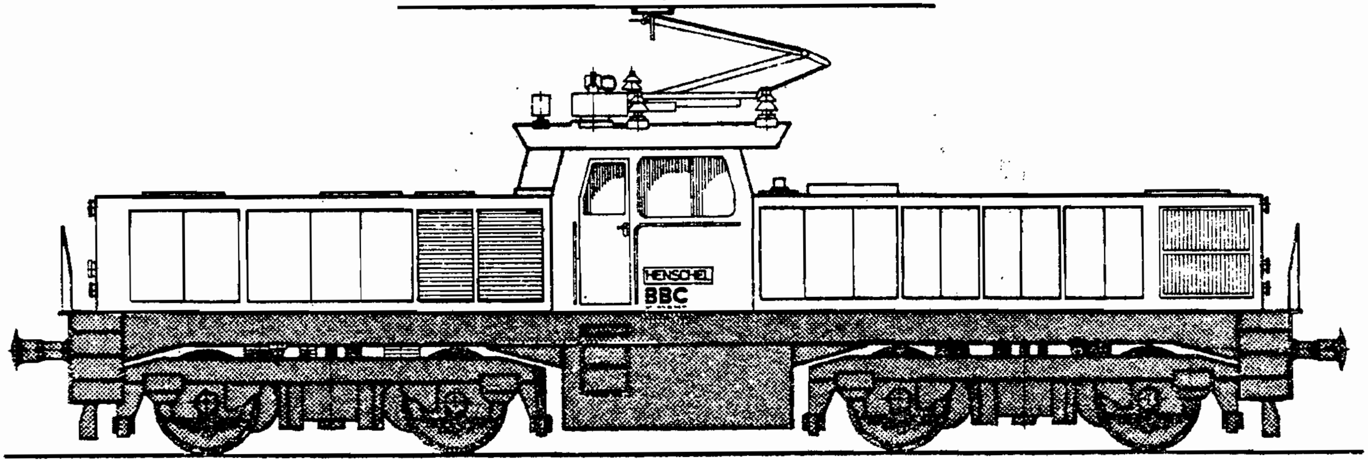
BBC
BROWN BOVERI

BBC three-phase traction system in electric locomotives for heavy industrial operation

Publication No.
D VK 70 175 E



15 kV, 16 2/3 Hz, 50 Hz



Ruhrkohle AG (RAG) Essen, ordered six electric lokomotives incorporating BBC asynchronous traction technique for heavy shunting and main line service on the network of the Zechenbahn und Hafenbetriebe Ruhr-Mitte, Gladbeck. The locomotives are in regular service now.

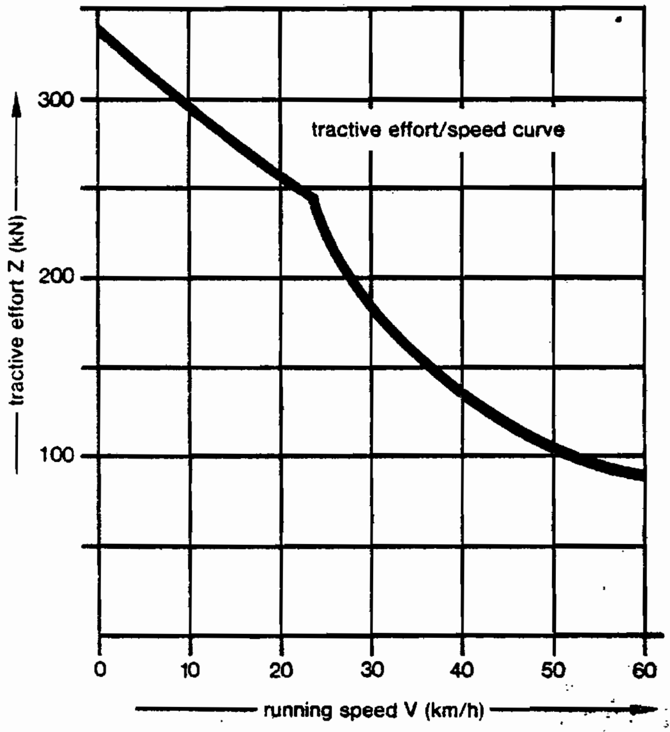
Main data

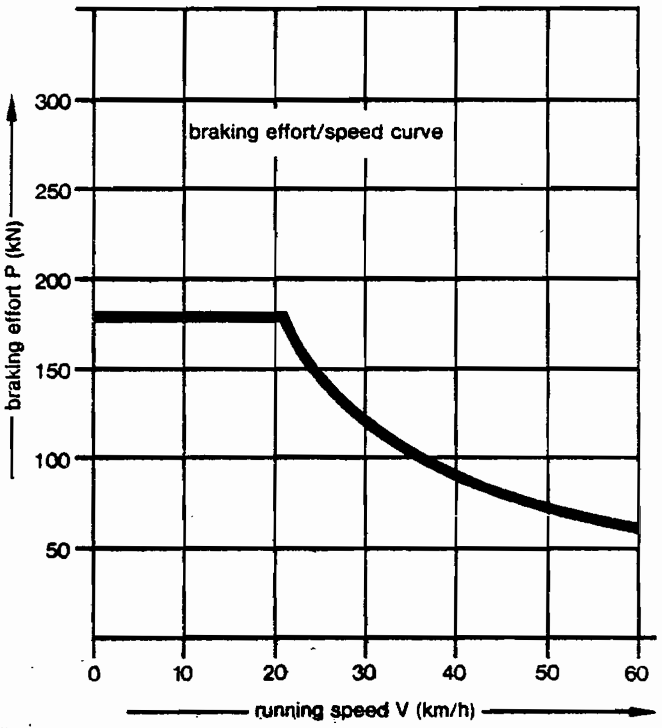
Catenary voltage	15 kV
Catenary frequency	$16^2/_3$ Hz or 50 Hz
Axle notation	Bo'Bo
Weight of locomotive	88 tons
Axle load	22 tons
Output at wheel rim	1,500 kW (2,040 HP)
Maximum speed	60 km/h (37 m.p.h.)
Tractive effort at starting	330 kN (appr. 33 tons, 72,800 lbs)
Power of electric brake	1,200 kW (1,630 HP)
Wheel diameter (new)	1,100 mm
Length over buffers	15,000 mm
Distance between centres of bogies	7,800 mm
Bogie wheel base	2,800 mm

Design: Typical industrial locomotive with central cab, diagonally arranged driving desks and low hoods.

Essential features of the BBC three-phase traction system

- Contactless operation during traction service
- Very high continuous tractive effort
- No slipping of individual axles, since all motors are connected in parallel
- Electric braking down to standstill
- Only little reactive power taken from the power supply system



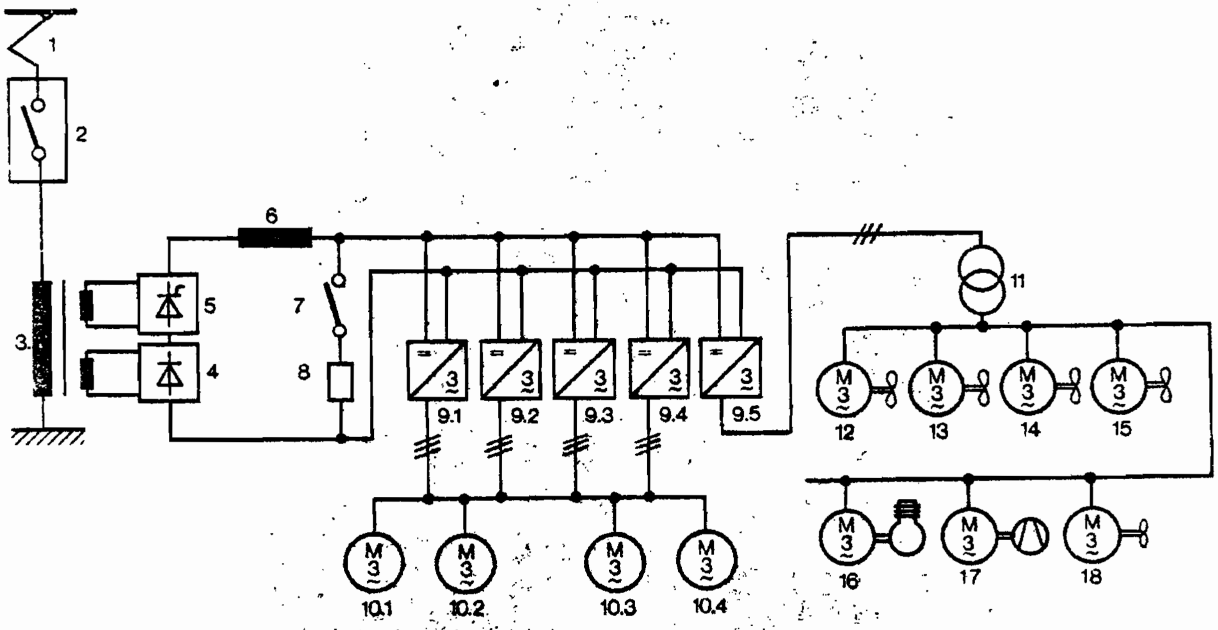


Main circuit diagram

The three-phase asynchronous motors are supplied with infinitely adjustable frequency and voltage through four inverters of type DE 2500 connected in parallel. Within the normal speed range between 0 and 60 km h, the traction motors require a frequency of 0.1 to 63 Hz. The inverter input circuits are connected to the dc intermediate circuit rated at 1,500 V. This voltage is supplied by two rectifier bridges connected in series. They are fed by two secondary windings of the main transformer.
To prevent the variations of the catenary voltage from influencing the intermediate circuit, half of one rectifier bridge is equipped with thyristors, thus keeping the dc voltage at a constant value. One reactor as well as some capacitors are used to smoothen the rectified voltage.
This three-phase equipment consisting of asynchronous traction motors, electronic inverters and control unit is, in fact, the same as the well-proven equipment of the HENSCHEL-BBC-DE 2500 locomotive.

Supply of auxiliaries

All auxiliaries of the locomotive (blowers for inverters, blowers for traction motors, oil pump of the transformer, compressor, driver's cab heating system, etc.) are fed by the board network 380 V, 50 Hz. The inverter for the auxiliaries consists of the same components as the main traction inverter.



1 Pantograph
2 Circuit breaker
3 Main transformer
4 Rectifier bridge
5 Semi-controlled rectifier bridge
6 Smoothing choke
7 Braking contactor
8 Braking resistor
9.1 to 9.4 Traction inverter
9.5 Auxiliary inverter
10.1 to 10.4 Asynchronous traction motor
11 Auxiliary transformer
12 Blower for rectifier
13 Blower for inverter
14 Blower for inverter
15 Blower for traction motors
16 Air compressor
17 Oil pump for transformer
18 Blower for transformer oil cooler

ATTACHMENT F

BBC
BROWN BOVERI

Developing a 15 kV single-phase electric locomotive with three-phase induction motors

By Joachim Körber

Brochure Order No.
D VK 60997 E

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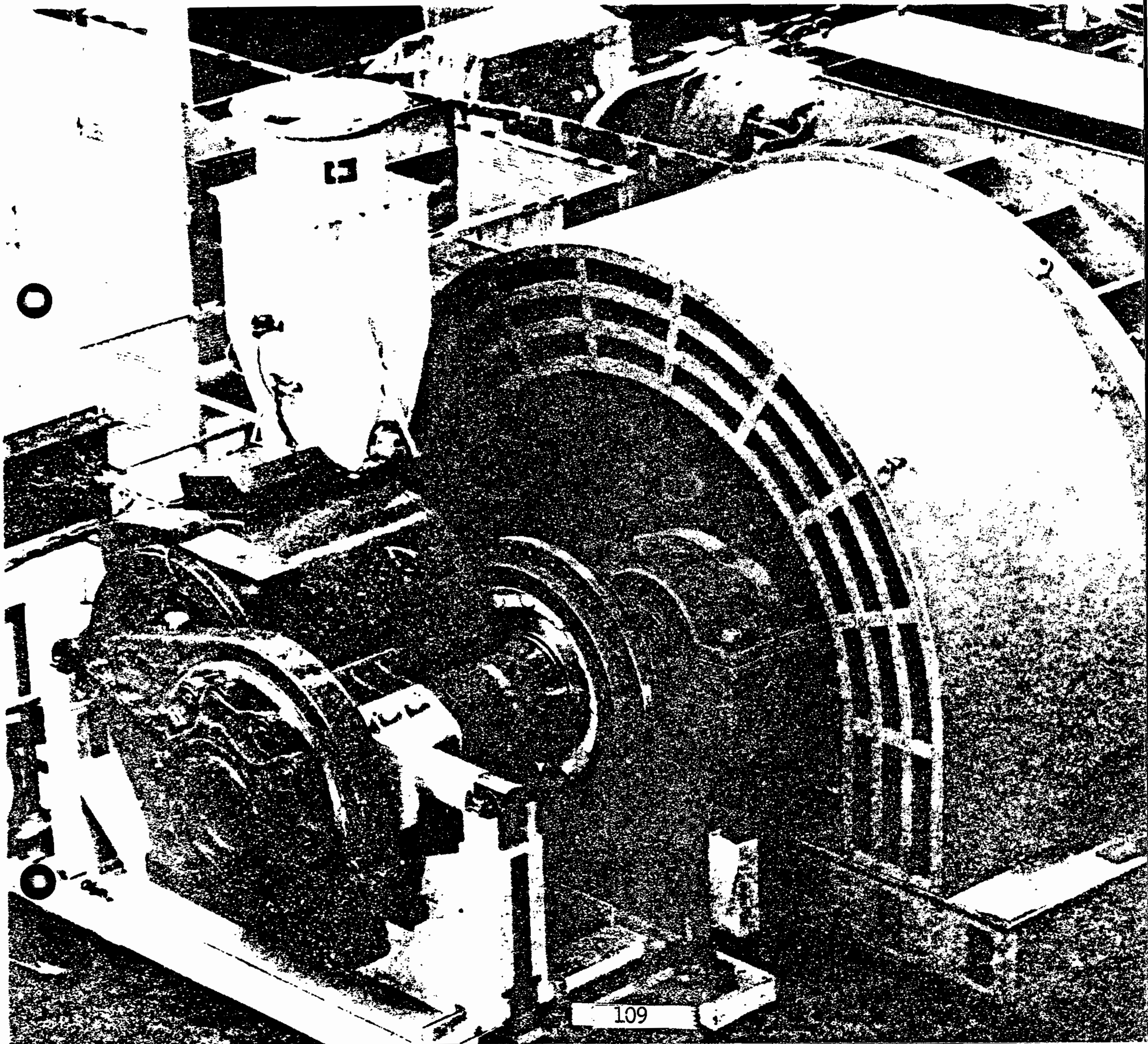
No. 10 — 1976, pages 381 to 384



Developing a 15 kV single-phase electric locomotive with three-phase induction motors

DIPL-ING JOACHIM KÖRBER
BROWN BOVERI & CIE, MANNHEIM

Die Entwicklung einer elektrischen Drehstrom-Hochleistungslokomotive mit Asynchronfahrmotoren—Die Entwicklung von 5 Lokomotiven einer neuen Baureihe E120 mit Drehstromfahrmotoren ist von der DB nach eingehender Erprobung mit 1971 von BBC Mannheim und Henschel gebauten Prototyp-Dieselelektrischen Lokomotiven in Auftrag gegeben worden. Die fünf Prototypen der neuen Baureihe sollen vier speziell entwickelten Fahrmotoren mit je einer Leistung von 1 400 kW erhalten und bei einer Inbetriebnahme 1978–79 den Weg für die Serienherstellung bahnen. Eine der ursprünglichen Diesellokomotiven wird zur Zeit umgebaut und für den Betrieb unter 1·5 kV Gleichstrom mit Gleichstrom/Gleichstrom/Wechselstrom Kraftumwandlung bei den Niederländischen Eisenbahnen hergerichtet

Le développement d'une locomotive à courant monophasé 15 kV avec moteurs asynchrones triphasés—Le développement de 5 locomotives E 120 avec moteurs asynchrones triphasés sans collecteurs a été ordonné par la DB après des essais approfondis avec des locomotives diesel-électriques prototypes construites en 1971 par les sociétés BBC Mannheim et Henschel. Un moteur de traction offrant une puissance de 1 400 kW a été mis au point pour l'installation dans ces machines Bo-Bo, qui doivent être mises en service en 1978–79; elles vont préparer le terrain avant que commence la fabrication en série. Une des locomotives diesel subit actuellement des modifications pour permettre des essais comme locomotive à courant continu 1 500 V avec conversion de puissance courant continu/courant continu/courant alternatif à bord

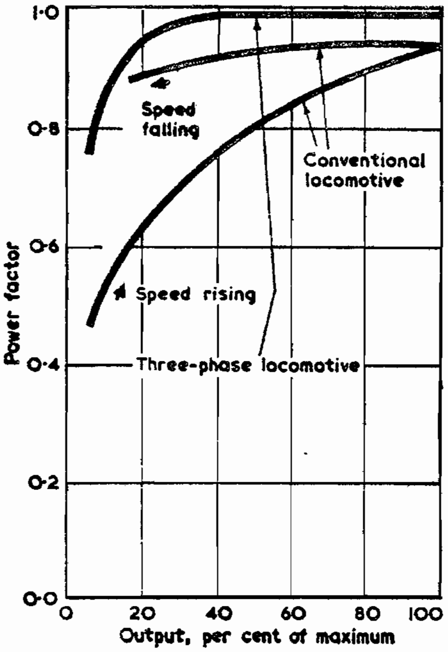
Desarrollo de una locomotora eléctrica monofásica de 15 kW con motores de inducción trifásicos—El DB ha pedido el desarollo de 5 locomotoras de la clase E120 con motores de tracción trifásicos sin escobillas, después de exhaustivas pruebas con los prototipos diesel-eléctricos construidos en 1971 por BBC Mannheim y Henschel. Se ha desarrollado un motor de tracción de 1 400 kW para estas unidades Bo-Bo, que entrarán en servicio entre 1978 y 1979 y que están destinadas a preparar el terreno a la producción en serie. Una de las locomotores diesel originales se ha convertido ahora, para uso en Holanda, en una locomotora eléctrica con conversión cc/cc/ac en el tablero

The development of five electric locomotives of Class E 120 with three-phase brushless traction motors has been ordered by the DB after extensive tests with prototype diesel-electrics built in 1971 by BBC Mannheim and Henschel. A 1 400 kW traction motor has been produced for these Bo-Bo units, which are to be placed in service in 1978-79 and are intended to pave the way for series production. One of the origina diesels is now being converted fo use in the Netherlands as a 1 500 V dc electric locomotive with dc/dc. three-phase power conversion

IMPORTANT strides are being made in the introduction of three-phase brushless traction motors. A recent decision by the German Federal Railway (DB) to develop five 15 kV 16⅔ Hz Bo-Bo electric locomotives with a 20-min rating of 5 600 kW, to be known as Class E 120, marks the transition from experimental motive power units to the prototype stage, from which series production orders may be expected to follow before 1980.

Brown Boveri & Cie AG of Mannheim co-operated with Henschel in building three diesel locomotives of 2 500 hp (RG May 1971) in order to demonstrate the advantages of the three-phase induction motor in traction service. These have always been recognised in principle by traction engineers, but only in the 1970s has the development of power electronics reached t point where it becomes economically possible to produce a three-phase supply of variable voltage and frequency on board a locomotive.

Development of diesel-electric locomotives with three-phase motors has continued, and the Swiss Federal Rail-



LEFT: *Fig 1. Comparison of power factors shows that a 15 kV 16⅔ Hz locomotive with three-phase drive gives much better results than a conventional locomotive with commutator motors*

ways (SBB) is about to place in service six heavy-duty diesel shunters of Class Am 6/6; these are six-axle units of 108 tonnes (RG June 1976). In addition, SBB would like to order six mechanically similar electric locomotives designated Ee 6/6 with three-phase motors.

The DB was more interested in developing electric motive power than diesel, having some 10 000 km of route already electrified, and arranged with BBC for a transformer, rectifier and smoothing circuit to be installed in a laboratory coach coupled to one of the three original diesels, which had its engine and alternator removed. This installation was described in RG February 1975, and it provided data on the basis of which the five electric locomotives of Class E 120 are now being constructed.

Meanwhile, the former diesel loco used in the DB experiments is undergoing further conversion so as to operate in the Netherlands as a 1 500 V dc experimental electric locomotive. Mention should also be made of the two German orders for a total of 12 industrial locomotives with three-phase motors (see box opposite).

DE 2500 experience

The first of the three original diesel-electric locomotives entered service on the DB in 1971-72. This was No 202 002 (the white-painted unit subsequently converted to straight-electric drive) with which the following performance figures were recorded:

Tractive effort at starting	27 tonnes
Tractive effort at 140 km/h	4 tonnes
Maximum speed	140 km/h
Output at the wheel-rim	1 300 kW

Extensive measurements demonstrated that the concept of an intermediate dc stage was right, and that the steep characteristic of the three-phase squirrel-cage induction motors driving the axles were such as to make separate protection against wheelspin unnecessary.

There was found to be room for improvement in the design and construction of a number of components, however, and these changes were incorporated in Nos 202 003 and 202 004 (the red and blue painted diesel units). These two are still operating in regular service on the DB.

More powerful motors

It was the possibility of installing a more powerful traction motor in the space available within the bogie that really attracted the DB to the idea of power conversion from single-phase ac through dc to drive three-phase motors. In 1972 the DB suggested to BBC that straight-electric application of the principles involved in the DE 2500 series should be investigated.

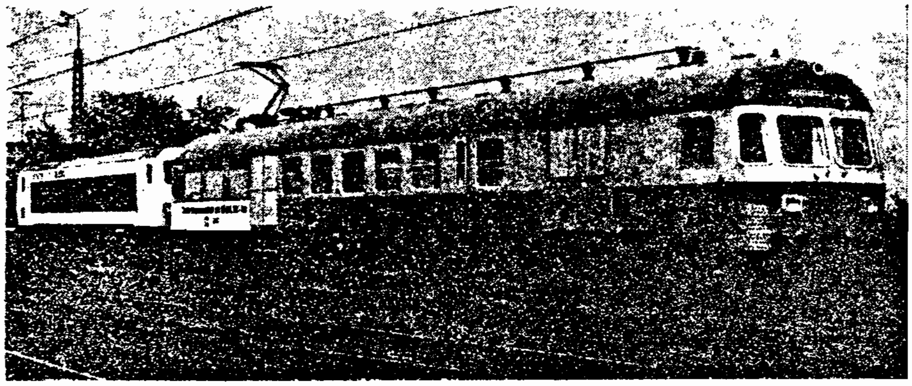
Where the traction supply is dc one must pay close attention to the harmonics generated by the dc/three-phase inversion process. In the case of the DB where the traction power system is 15 kV 16⅔ Hz, it is also necessary to ensure that the conversion from single-phase ac to dc does not adversely affect the supply network.

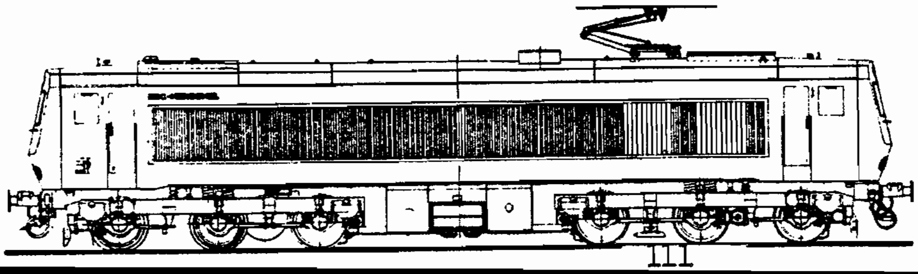
Ideally, ac power should be taken in sinusoidal waveform at unity power factor; that is, with the current exactly in phase with the voltage. The power factor for locomotives with phase-angle control might well be better than convention locomotives with ac commutator motors (Fig 1).

Where a dc stage is introduced between the motors and the supply it is possible to take power in a more satisfactory form. It is the use of the four-quadrant controller—a current regulating device consisting of active and passive filter elements—which makes the provision of a stabilised dc intermediate stage feasible. This stable intermediate dc supply cannot be achieved by using a normal thyristor bridge—not without a considerable penalty in cost and weight, anyway.

First a 200 kW version of the proposed power conversion equipment was erected in the BBC laboratories; it consisted of a four-quadrant controller, a filter, inverter and motors. When supplied at 15 kV 16⅔ Hz the power factor was found to be 0·98 as predicted mathematically.

It was at this stage in 1974 that the





ABOVE LEFT: *The original white-painted DE 2500 prototype diesel locomotive No 202 002 was used for trials on the DB as a 15 kV 16⅔ Hz straight electric with some equipment mounted in a DB laboratory coach. Now it is being converted to accept the NS traction supply of 1 500 V dc (Fig 2, LEFT), but in this form it will only have a single QD 646 traction motor driving the centre axle of one bogie* experimental locomotive consisting of No 202 002 coupled to a DB laboratory coach was created. The diesel engine, alternator and cooling systems were removed and replaced by ballast weights. A pantograph, transformer, rectifier and dc smoothing circuit were installed on the laboratory coach. Tests continued through the winter of 1974-75. The results were very satisfactory. Power factor was found to be 0·99, while the overall power conversion efficiency was somewhat better than that of a conventional electric locomotive. Because of the excellent current regulation, it was possible to achieve a total output of 1 300 kW.

No less important, the harmonics likely to cause interference with signalling or communications were within acceptable limits. Loss of contact through pantograph bounce is no real problem because the commutation circuits of the four-quadrant controller are charged by the intermediate dc circuit.

The full installed output of the inverter can be used regardless of fluctuations in the traction supply voltage, since these are ironed out by the four-quadrant controller. As this device can operate in reverse as an inverter, it is possible to regenerate power into the overhead line when braking.

This locomotive operated in Germany and Switzerland hauling trains of up to 2 000 tonnes. No failure in service occurred in 20 000 km of operation.

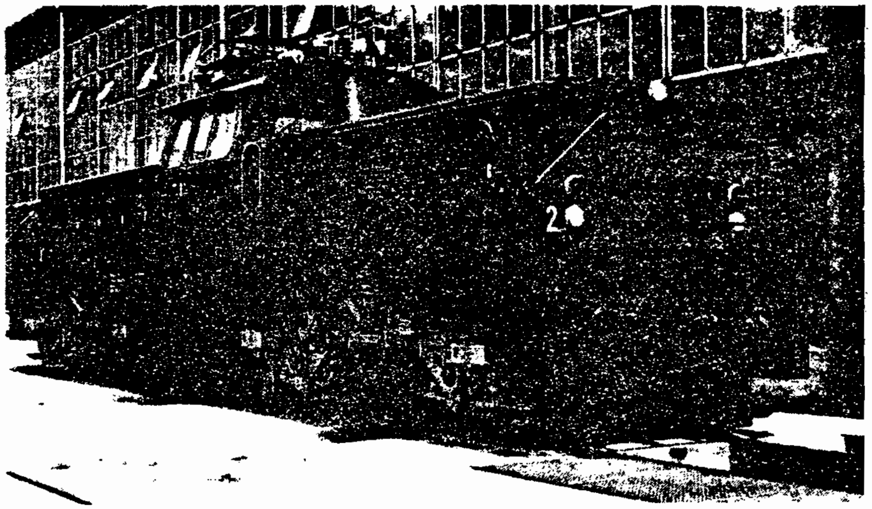
Scaling up the tests

The next stage was to move from a nominal 200 kW per axle up to 1 400 kW, the power specified for the DB's new E 120 class. Once again, equipment was set up on the test bench because a motor rated at 1 400 kW had not hitherto been applied to traction.

The four-quadrant controller and inverter were located together in a new compact unit to save space and to simplify measurement, and an air cooling system (later an oil cooling system) was installed to remove waste heat. Including the oil pumps and radiator, the power conversion equipment for one ac three-phase motor now weighs only 1 800 kg. The motor itself weighs 2 400 kg.

This equipment was run on the test-bed at a simulated speed of 160 km/h. As a result, the tractive effort and power output specified for the E 120 were increased as the specifications were then in course of preparation. The QD 646 traction motor will be used since a temperature rise of 155°C above ambient was not exceeded even on lengthy test runs.

The efficiency of the QD 646 traction motor is better than that of a commutator motor. This is borne out by



First three-phase electric locomotive delivered

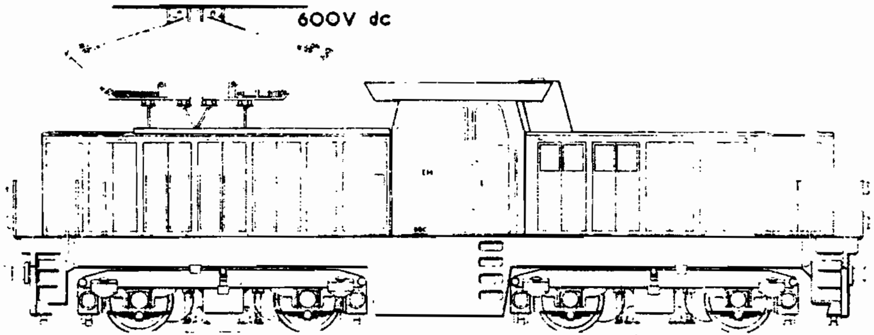
HANDING OVER THIS MONTH of the first three-phase electric locomotive built by BBC Mannheim and Thyssen-Henschel of West Germany to Zechenbahn und Hafenbetriebe Ruhr/Mitte AG of Gladbeck (RAG) marks an important milestone in the development of three-phase traction. A series of six of these Bo-Bo locomotives is being delivered to RAG.

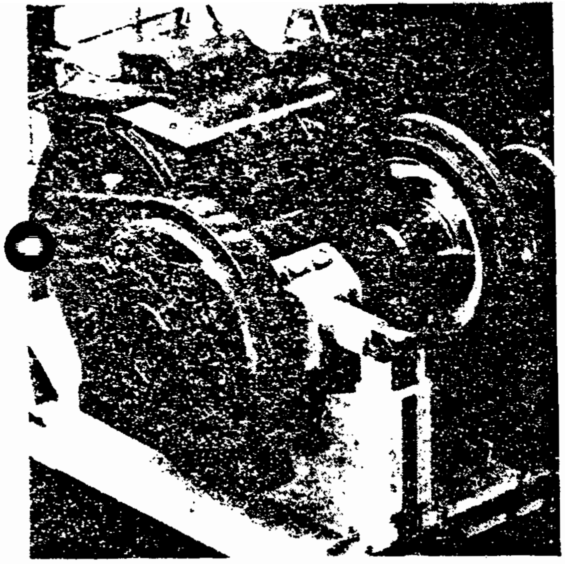
ABOVE: *The first of six Bo-Bo industrial locomotives which can accept 15 kV at 16⅔ Hz or 50 Hz will be delivered to RAG this month from BBC Mannheim and Thyssen-Henschel.* BELOW: *Also under construction are six electro-diesel locomotives with three-phase drive for Eisenbahn und Häfen of Duisburg*

Designed for heavy industrial working, the centre-cab RAG locomotives have a 10-min maximum output of 1 500 kW and a continuous rating of 1 200 kW. Power supply from overhead is at 15 kV 16⅔ Hz and 50 Hz. The three-phase power transmission system and the four QD335N4 traction motors are virtually identical to the equipments used on the prototype DE2500 diesel-electric locomotives produced speculatively by BBC in 1971.

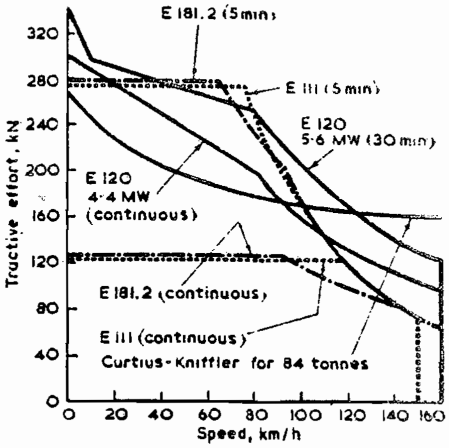
One factor influencing RAG's choice of three-phase machines is the dirt-laden atmosphere in which the locomotives will operate. The totally-enclosed three-phase motors thus have important advantages compared to conventional motors. Likely dirt deposits demanded also that three-phase current should be used for the auxiliaries and 380 V 50 Hz circuitry from a separate rectifier supplied from the intermediate dc circuit was adopted. Total weight of the 15-m long locomotive is 88 tonnes and maximum speed 60 km/h.

Also under construction by the same manufacturers are six electro-diesel Bo-Bo locomotives. With 600 V electric operation they have an output of 1 000 kW and in the diesel mode 500 kW. Weight is 100 tonnes and maximum speed 40 km/h.





LEFT: *A new three-phase squirrel-cage traction motor of exceptional power, the QD 646, has been developed for the Class E 120 locomotives. This motor can accept 1 400 kW continuously*



RIGHT: *Fig 4. Tractive effort/speed characteristic of the E 120 class compared with DB's existing E 111 and E 181.2 locomotives*

the requirement for cooling air which is almost halved. The overall efficiency of the E 120 locomotive will be at least as good as conventional units with tap-changer control.

Field tests have shown that the traction motors may be used at their maximum power of 1 400 kW continuously. The same applies to the current regulating system, the four-quadrant controller and inverter. Only the transformer with its high time-constant is subject to thermal limitations.

Dutch interest

If the four-quadrant device can be used both to rectify and regulate single-phase ac, the next logical step is a one-quadrant controller to receive direct current, such as the 1 500 V dc traction supply of the Netherlands Railways (NS). This is a much simpler problem, given a constant output voltage, since there is no input waveform.

It is actually possible to adapt the current regulating circuits to convert a line input voltage ranging from 900 to 1 800 V into a constant intermediate dc supply to the inverter of 2 100 V, or even more.

From the point of view of minimising reactance, it is better to produce an intermediate supply of constant voltage rather than constant current; this applies both to ac and dc traction supply systems. Again, a dc intermediate circuit is to be preferred even with a dc traction supply.

This means that all the components developed for the ac locomotive can be used with dc once the intermediate constant-voltage dc circuit is established. The bogies of ac and dc locomotives would be identical.

Each one-quadrant controller is separated from the overhead wire by a choke which limits the build-up of current, but by using several such regulators operating at a different phase relationship the total reactance of this stage can be kept to a low figure. Losses can also be minimised by taking some care over the sequence in which the controllers are triggered, and interference with signalling is thereby reduced.

At present BBC and Henschel are reconverting No 202 002 for operation in the Netherlands at the request of the NS. The large QD 646 traction motor designed for the E 120 will be used, but No 202 002 (which is a six-axle machine) will run with only the centre axle of one bogie driven by a single motor (Fig. 2).

The most important measurements to be made are on the traction supply network, but the adhesion achieved by a single high-power asynchronous three-phase motor will also be assessed. As the wheel diameter of No 202 002 is smaller than will be the case on the E 120, two-stage gearing will be necessary.

The E 120 class

Carefully staged development of ac traction and extensive experiments with the new 1 400 kW motor caused the DB to order from BBC the construction of electrical equipment for Class E 120 in May 1976. These will be Bo-Bo units continuously-rated at 4 400 kW with a 20 min rating of 5 600 kW. The principal circuit diagram is in Fig. 3. Comparison of the tractive effort/speed characteristic (Fig. 4) with existing DB four-axle locomotives shows that the E 120 will be able to handle both fast passenger and heavy freight trains, since it combines high tractive effort at the maximum speed of 160 km/h with a high continuous power rating.

On most of the DB's electrified lines the permitted axleload is 21 tonnes. Out of the total permissible weight of 84 tonnes for the E 120, the electrical equipment weighs 47 tonnes leaving 37 tonnes for the mechanical parts. The two bogies will weigh only about 15 tonnes compared with 22 tonnes using conventional motors. This low bogie weight will mean less wear on the track.

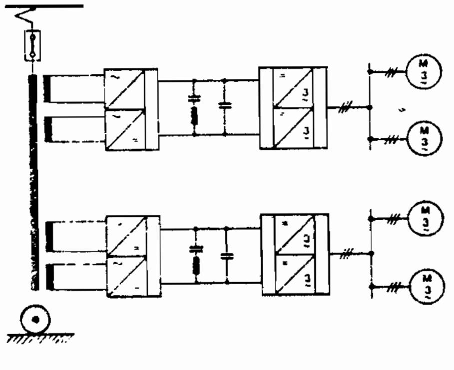
Delivery of the five prototype E 120 locomotives is scheduled for 1978-79. The principal advantages which they will offer may be summarised as

- better use of available adhesion;
- lighter bogies;
- lower maintenance costs;
- available for passenger and freight service;
- high power factor, even at low speed;
- automatic compensation for weight transfer between bogies.

Staged development

We have arrived at this point through a number of logical stages. Both the manufacturer and user were faced with new technical problems, but much knowledge has been gained on the test-bed and through running trials. This is one of those areas where systematic research and development involving both manufacturer and user is necessary to minimise the economic risk involved.

No doubt the E 120 will have its teething troubles, but it can already be predicted with some confidence that the three-phase brushless traction motor will prove universally applicable to all traction systems. They can form the basis of high speed traction as well as providing an economic solution to other traffic demands. ■



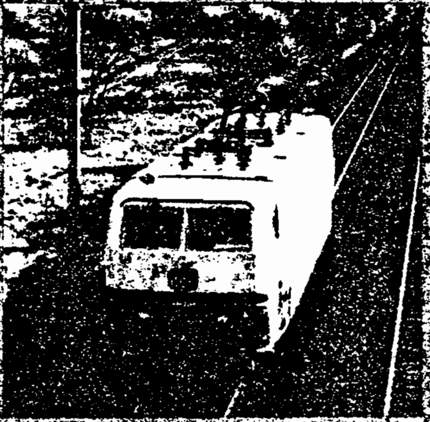
LEFT: *Fig 3. The E 120 class will have four transformer secondary windings each supplying a rectifier. Smoothed dc is then fed to four-quadrant controllers which deliver three-phase power to the motors; these are connected in parallel pairs within each bogie*

ATTACHMENT G

AEG Two-Frequency A.C. Locomotive series 181 of German Federal Railway (DB) with sector control (LUB) of AEG-TELEFUNKEN

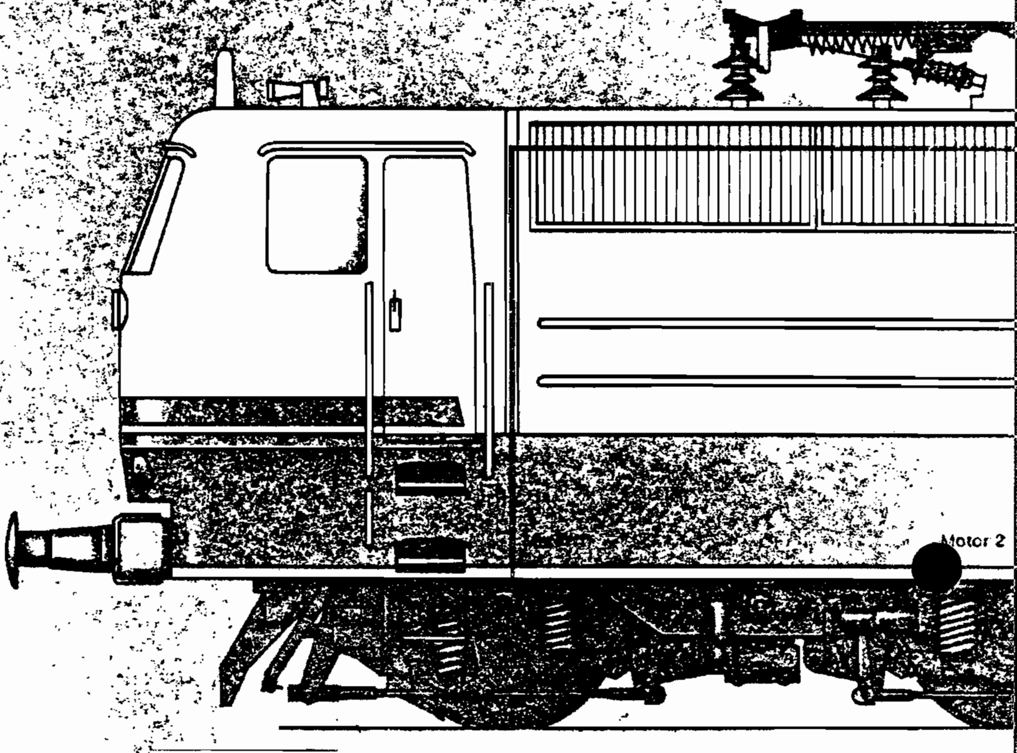
Sector C
from AEG-TEL
maintenance free-re

The electrification of the Moseltal-trunkline from Koblenz to Trier provides an additional connection between the electrified railway lines of Germany and those of Luxembourg (CFL) and France (SNCF). For the resulting international traffic under different electric systems (DB 15 kV, 16⅔ c/s, CFL/SNCF 25 kV, 50 c/s), the German Federal Railway (DB) in 1972 placed orders with AEG-TELEFUNKEN (electrical part) and Fried. Krupp (mechanical part) for 25 mixed traffic locomotives of series 181.2 for fast passenger and heavy freight service. These locomotives were designed on the basis of prototype locomotives developed by the same companies.



The demand for universal use of the locomotives led to the decision to apply thyristor control and d.c. traction motors for undulated current. Consequently, automatic control of traction and rheostatic braking effort is completely stepless and enables highly dynamic operation by means of GEATRONIC components in INTERMAS modules of AEG-TELEFUNKEN.

Each locomotive has two rectifier groups, each feeding two traction motors and, by separate control of both of them, providing an optimum compensation of axle-load transfer and of wheel-slip. Each rectifier is composed of two unsymmetrical semi-controlled bridges in sequence control and provides facilities for self-commutation by means of capacitors and turn-off thyristors, thus reducing reactive power consumption and ensuring a high compatibility with the feeding system. This self-commutating circuit is called LUB, as an abbreviation of "Löschbare unsymmetrische Brücke" ("extinguishable unsymmetrical bridge").

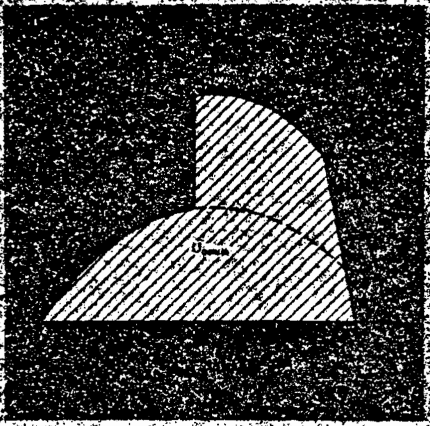


[illegible] LUB rectifiers [illegible] economical.

[illegible]

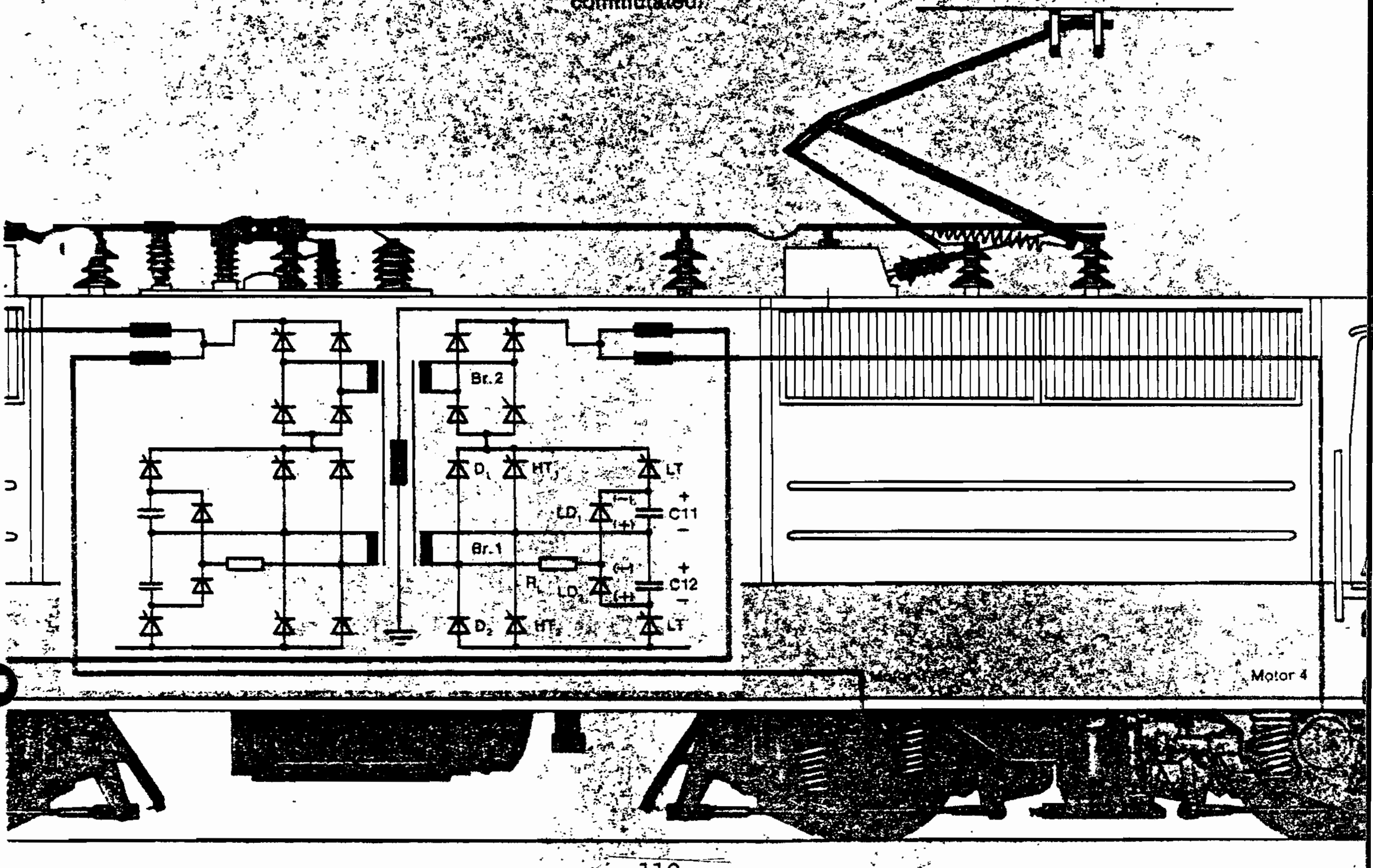
Bridge No. 1 of each rectifier is extended by a commutation device, which consists of:
the commutation capacitors C 11 and C 12, the turn-off thyristors LT 1 and LT 2, the charging diodes LD 1 and LD 2, and the charging resistor RL.

This supplementary equipment is connected in parallel to the main thyristors HT 1 and HT 2. By means of the charging diodes and the charging resistor the commutation capacitors are charged from the secondary winding of the main transformer with the peak voltage of the preceding half cycle (according to the polarity shown in the picture). Thus the instantaneous readiness for commutation is secured. The capacitors are so dimensioned as to grant a sufficient turn-off time for the main thyristor HT at the momentary current to be commutated.

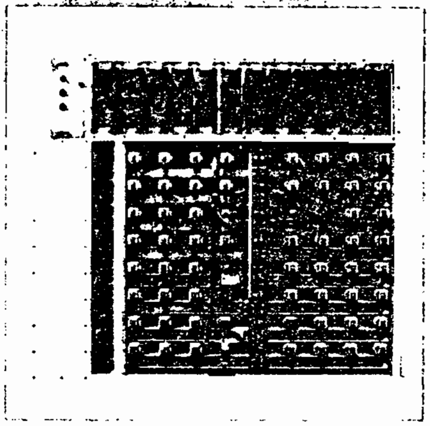


... and these are the advantages [illegible] rectifier

Under service conditions of a mixed traffic locomotive with loads and speeds varying within a wide range, the highest reduction of reactive power is achieved, if and when the commutation circuit is already effective at low voltages (corresponding to low speed) and remains effective over the whole range of voltage (or speed) control. Therefore self-commutation is initiated already in the first bridge of the sequence control. Self-commutation remains effective also after maximum voltage is attained in the first bridge and during voltage control of the second bridge (50...100 % of the traction motor

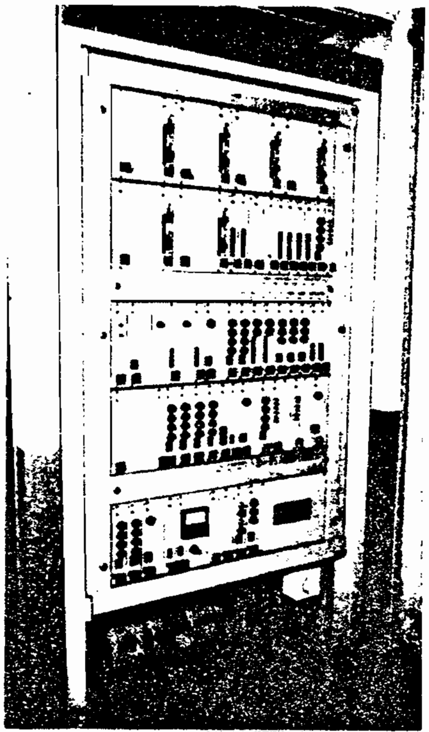


voltage), because the extinguishing commutation of current is always forced by the self-commutation device in either of the two bridges. In order to keep the reactive power consumption low, starting of the locomotive begins with normal phase shifting control by firing at first the LT's, then by firing the HT's, and finally the turn-off angle of the LT's is governed by current and voltage. By these means it is possible to obtain a quasi-linear rise of feeding current in the contact wire within the voltage range of about 33 %...100 %, corresponding to the effective real power at the wheels.
AEG-TELEFUNKEN rectifier equipments offer the most economical and well-proven solution for electric locomotives which shall have full performance under all feeding conditions and systems.
Working contactless and stepless, with low maintenance requirements, capable of high current and voltage, rectifiers from AEG-TELEFUNKEN do cover all demands in ordinary and automatic control with a minimum of reactive power in the feeding system. As an important consequence a power factor greater than 0.9 can be achieved.

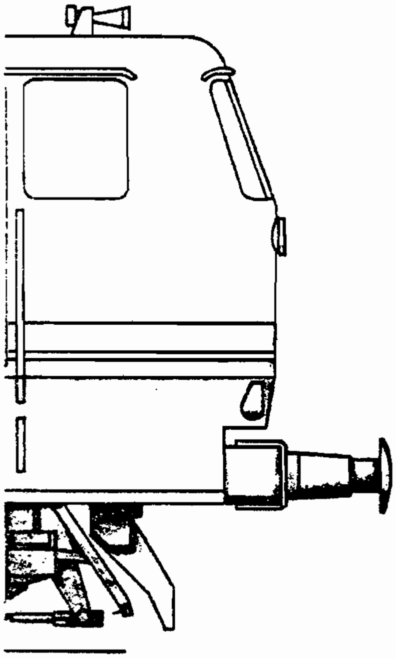


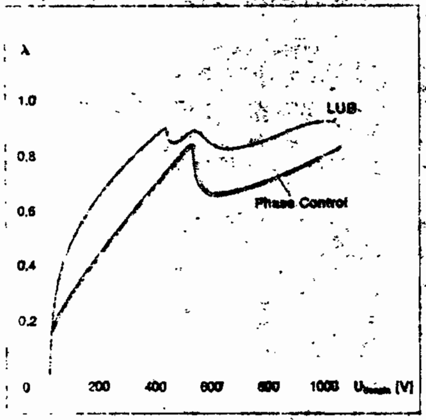
Cubicle for feeding 2 motors.
$U_d = U_{contin.} = 1050$ V
$I_{dmax} = I_{max} = 3000$ A
$I_{dnenn} = I_{contin.} = 2500$ A
The commutation caqacitors are qart of the static converter cubicles.

Dimension:
Width 2000 mm
Height 1785 mm
Deqth 500 mm



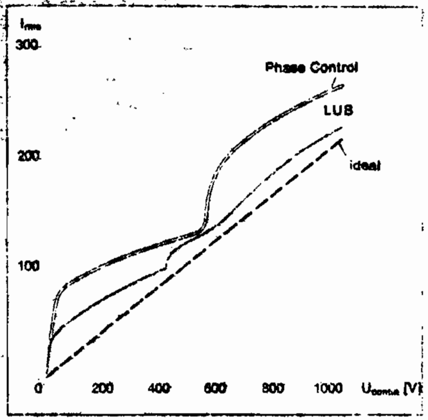
The control cubicle system GEATRONIC-dust proof with external ventilation-comprises: Comqonents for armature voltage control and current control, brake control, slip protection as well as firing pulse and commutation pulse generating.





Characteristic of total power factor

$$\lambda = \frac{\text{active power}}{\text{apparent power}}$$



Characteristic of supply current at rated motor current

Additional comments:

The German Federal Railway recently have measured the reactive power consumption of LUB equipped trains on various lines and under different conditions by means of power counters. The **average** power factor for all locomotive runs, including starting, running and braking was 0.89...0.94. The corresponding figure for locomotives with conventional thyristor control is abt. 0.75...0.82. Railway Organisations considering fresh introduction of a.c. traction can calculate the economies on fixed installations by applying LUB to the locomotives on the basis of their specific traction programme envisaged. On principle, the substation power to be installed, can be lower and the distance between substations can be longer (due to lower voltage drop on the contact wire). For Railway Organisations already operating a.c. traction, increasing traffic with increasing power demand can be handled for longer periods without installing additional substations or increasing the power of the existing substations.

The introduction of self-commutated (extinguishible) unsymmetrical bridge connection (LUB) is an essential contribution to the development of electric rail-traction, as it excludes the reactive power problems of conventional thyristor control and thus undisputably makes this techniques being the very solution for a.c. locomotives and emu's.

AEG-TELEFUNKEN have experience for sale.

Technical Data

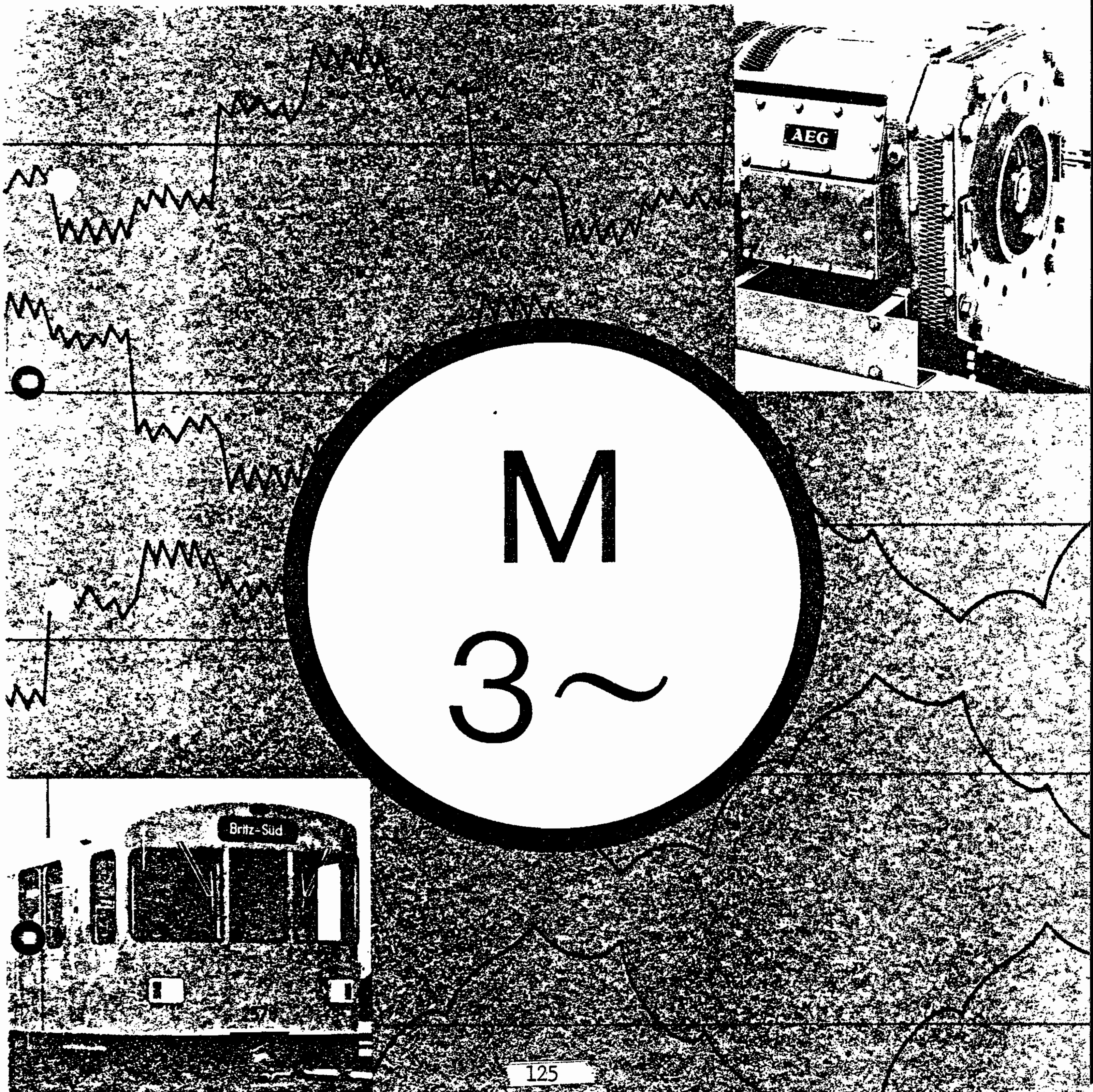
Electrical part	AEG-TELEFUNKEN Berlin
Mechanical part	Fried. Krupp GmbH., Essen
Delivery into service	1974
Track gauge	1435 mm
Supply system	1 ~ 16²/₃ c/s, 15 kV and 1 ~ 50 c/s, 25 kV
Wheel arrangement	Bo'Bo'
Maximum speed	160 km/h
Rated power (contin.)	3200 kW
Continuous rating	92 km/h and 126 kN tractive effort
Rectifier max. output	6100 kW
One-hour-rating	3300 kW at 90 km/h and 133 kN 3500 kW at 136 km/h and 92 kN
Max. tractive effort at starting	277 kN
Starting performance	5100 kW (5 min) at 66 km/h
Elect. brake Braking power (contin.)	2500 kW
Braking power (short time)	5100 kW
Braking effort	115 kN
Traction motor type	UZ 11664 K1
Number of traction motors	4
Gear ratio	3,16:1
Wheel diameter (new)	1250 mm
Length over buffers	17940 mm
Distance between bogie centres	9000 mm
Wheel base for bogies	3000 mm
Total wheel base	12000 mm
Max. height above rail	3660 mm
Max. width	3050 mm
Weight of the electrical equipment	43.0 t
Weight of the mechanical part	40.0 t
Weight in working order (Static adhesive weight)	83.0 t

AEG-TELEFUNKEN

ATTACHMENT H

AEG

Three-phase drive systems
for underground railways
and rapid transit vehicles



G. Cießow, G. Götz, P. Grumbrecht

Three-phase drive systems for underground railways and rapid transit vehicles

In the last few years a radical change has taken place in the technology of drive systems for rapid transit vehicles. Instead of cam or contactor controls that have been used up to now d.c. chopper controls were applied in several cases [1, 2]. Traction motors, however, remain to be series-wound motors and partly d.c. shunt-wound motors as well. Such a use of power electronics in the drive systems made energy savings possible, resulting from the absence of starting losses and the regenerative brake now feasible. The reduction of the number of contactors in the power circuit means a significant reduction of maintenance. On account of stepless control, a considerable improvement of the riding comfort took effect. Now, the development of d.c. choppers has reached the series production stage level causing them to be applied to a greater extent [3].

The technology of drive systems using three-phase traction motors should be regarded as the next step in this development. For the power supply of three-phase induction motors without commutators a special converter system is necessary on the vehicle, transforming the direct current of the contact line into three-phase a.c. current. The rapid progress in the technical perfection of the semiconductors for power electronics and data processing makes it possible to apply the three-phase technology for electric traction on suburban vehicles [4].

In order to test this system under operating conditions, AEG-Telefunken and Orenstein & Koppel have decided to produce a prototype three-phase drive equipment to be installed on a modern underground coach. Berliner Verkehrs-Betriebe (BVG) agreed on implementing these tests in actual operation on a new series F 76 two-car unit.

In the following, the basic principles of this technology are outlined as well as some details given on the drive equipment now in operation:

1. Fundamental working mode of a three-phase a.c. system

The block diagram of a converter-fed induction motor is given in Fig. 1. Supply of the three-phase motor from the d.c. line common in rapid transit is effected via a converter system transforming the d.c. values U_d, I_d into a.c. values of variable frequency f. and variable voltage and current U and I_1. The control of these values takes place subject to the operational condition of the machine (speed n, torque M) through the electronic control unit.

The torque of an induction motor can be adjusted by presetting the stator current i_{1W} and the rotor frequency f_2 in the reference value generator SB. The stator frequency f_1 results from the preset value f_2 and the actual rotational frequency f_n measured by means of the tacho-generator G. Computing takes place in frequency adder IF.

The instantaneous value of the motor current i_{1x} is compared with the reference value i_{1W} received from IF. This control signal is used for setting the pulses in the converter control unit US for coordinated firing of the thyristors.

The fundamental tractive effort/speed characteristics achievable by means of a converter drive are shown in Fig. 2. There are two ranges of operation depending on the magnetic flux; below the "type point" (in Fig. 2 a marked for $n^* = 1$). For $n^* < 1$, the maximum flux of the machine is always attainable. The rating of the converter allows a constant maximum torque M^*; the corresponding stator current I_1^*, motor voltage U^* and rotor frequency f_2^* are indicated in Fig. 2 a.

Above the "type point" for $n^* > 1$, the motor voltage cannot be further increased proportional to the speed n^*. This causes a flux weakening of the machine and consequently a decrease o[illegible] torque. By raising the rotor frequency f_2^* the torque decreases almost inversely proportional to the speed.

In the whole speed range each torque below this limiting curve M^* can be adjusted, favourably influencing the flux of the machine by controlling the other electrical values well combined in an adequate way.

Varying these typical characteristics of values, e.g. raising the torque for $n^* > 1$, is possible, but results in an uneconomical design of the converter and the motor.

Fig. 2 b shows the characteristics of the input d.c. values of the converter for a given constant d.c. voltage U_d^*. The direct current I_d^* is proportional to the power P^*.

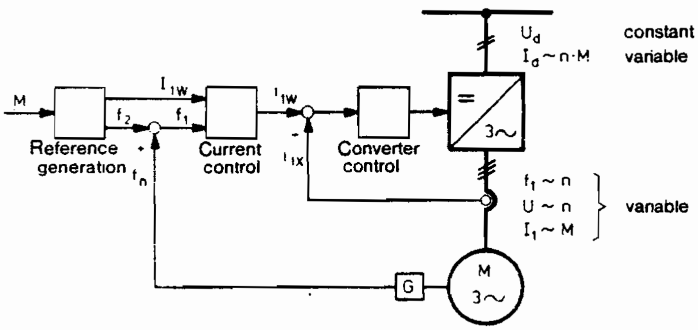
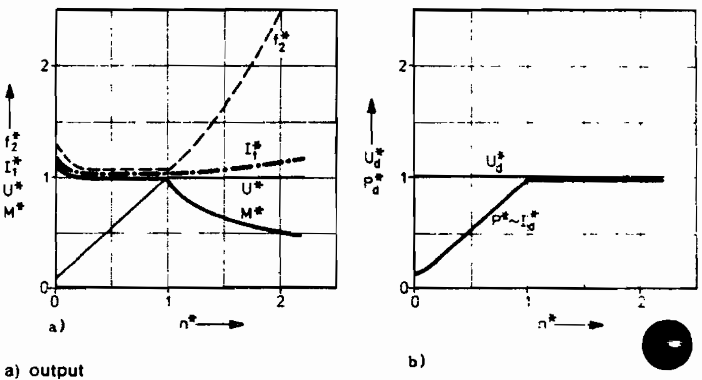


Fig 1 Converter-fed induction motor (schematic diagram)



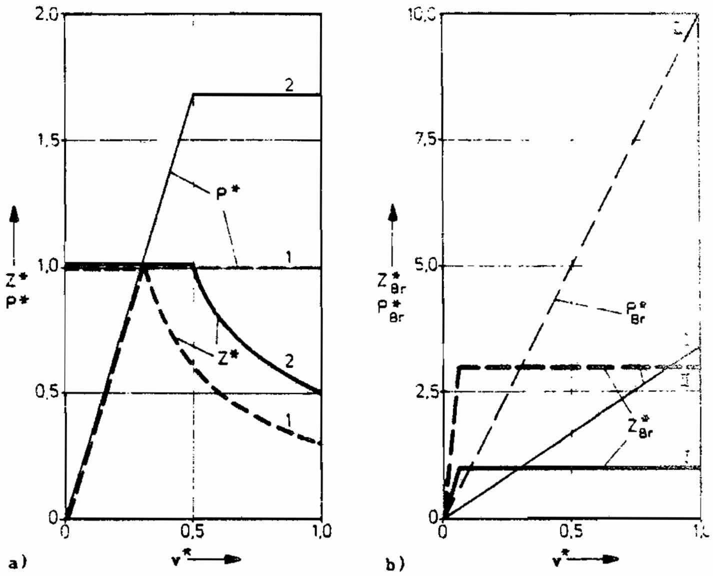
a) output
b) input
The asterisked values refered to nominal data

Fig. 2: Basic speed characteristics with maximum torque utilization

2. Requirements of a three-phase drive system for a rapid transit vehicle

The requirements of a three-phase drive system in suburban traffic are primarily orientated to the characteristics of existing transport systems. At present, the power capacity of the converter system must be adjusted to the operating performance of conventional vehicles. Supply systems with direct line voltages of 600 V and 750 V (partly up to 1500 V) with the corresponding significant variations are available. Additional, defined peak overvoltages must not affect the adaptibility of the system (see relevant VÖV, IEC recommendations).

The corresponding tractive effort/speed characteristics are indicated in Fig. 3. Fig. 3 a shows the characteristics in the motoring mode. The tractive effort characteristics Z^* of conventional vehicles are designed predominantly between curves 1 and 2 with low or high nominal speed. Relevant curves of the power P^* at the driving wheel have been included. High maximum power naturally results in a higher acceleration in the upper speed range, but it requires a significantly increased output rating of the converter. These interrelated facts have to be paid attention to, as a determination of the characteristics plays a decisive part in dimensioning the converter.



a) Motoring
1: v_{typ} = 0.3 v max.
2: v_{typ} = 0.5 v max.

b) Braking
I : $Z_{Br} \approx Z$
II: $Z_{Br} \approx 3 \cdot Z$ (rapid transit vehicles)

Fig. 3: Characteristics for tractive effort, braking effort and power

The brake effort requirements of a suburban vehicle also depend on whether or not the specific vehicle operates in regular street traffic. In this case, the emergency braking effort is required to be approximately three times the value of the starting tractive effort. (Fig. 3 b). The braking effort for vehicles not operating in street traffic nearly corresponds to the single value of the tractive effort. These requirements lead to the power curves indicated, which in extreme cases demands the tenfold value of the traction power. These relationships explain that dimensioning of the converter system is mainly subject to the braking requirements. In case of a high emergency braking power, it could be more favourable to make use of additional mechanical brakes in addition to the lower rated electrical brake.

Suburban vehicles should preferably be equipped with a dynamic brake that is indepedent of the supply system. The possibility of applying a regenerative brake for the regeneration of energy should be taken advantage of, if available without increased expenditure. A continuous checking of the receptivity of the line and an immediate stepless electronic switchover between regenerative and dynamic braking appears to be necessary.

Vehicles with three-phase drive systems put into operation in existing systems in the future have to be designed in such a way that they can operate together with conventional vehicles in multiple unit working. This limits the possibilities offered by a stepless tractive effort control of the three-phase a.c. system. Additional control devices are then necessary for the adjustment of the characteristic curves.

3. Applicable converter systems

Fig. 4 shows various possibilities to convert d.c. into three-phase a.c. systems by means of static converters.

There are single-stage and two-stage systems, with the two-stage systems including internal link circuits for energy storage. In case the energy storage components are predominantly capacitive, the converter system is characterised as one with impressed voltage. In case energy storage is by means of reactors, the system is current impressed. In voltage impressed systems the transition from motoring to braking is effected by reversing the direction of the current, while with impressed current systems the transition from motoring to braking takes place by reversing the voltage in the link circuit.

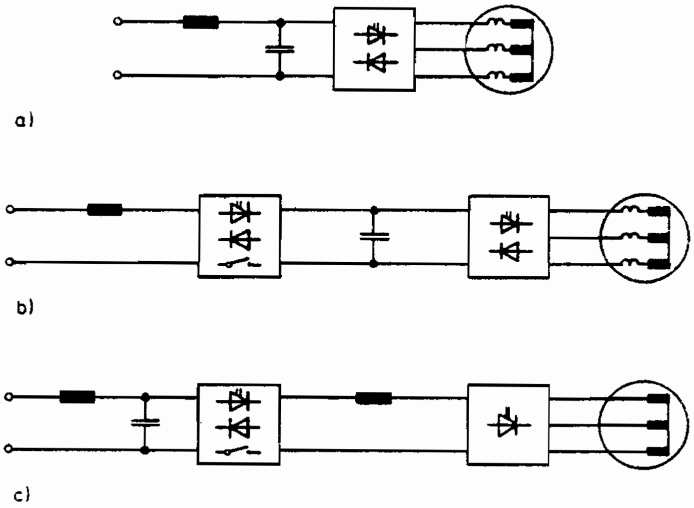
The single-stage configuration according to Fig. 4a includes a pulse width modulated inverter that produces the alternating variables of variable voltage and frequency by direct conversion from the direct line voltage. Voltage adjustment is effected by repeatedly pulsing the d.c. voltage within one half cycle of the motor frequency. Because of the limited pulsing frequency of the inverter a certain inductance of the load is required for limiting the harmonics in the current. It can be achieved by increasing the normally insufficient stator leakage of the motor, or by connecting additional series chokes. In the converter shown, the direction of the input current flow is determined by the direction of the energy flow. In each of the branches the converter requires an antiparallel circuit of diodes and self-commutated thyristors. In this way the converter can control the transfer from the motoring to the braking mode without contacts by static means. An L-C-filter must be provided between the supply and the drive system in order to limit the disturbing effects of harmonics. The pulse width modulated inverter has to be designed under due consideration of the line voltage tolerances referred to before.

Fig. 4 b shows a two-stage converter system with the same configuration of the pulse width modulated inverter and motor. A d.c. chopper is connected ahead which makes it possible to control the link circuit voltage to a constant value which is always higher than the maximum value of the supply voltage. A d.c. chopper for two directions of the energy flow (transfer from motoring to braking) has to be provided for this scheme.

To minimise the number of semiconductors in its internal circuitry, power switching contacts may be provided. As a result of the close control of the link circuit voltage, the application of this converter system makes it possible to employ a pulse width modulated inverter of a smaller type rating than indicated in Fig. 4 a.

Unlike the configurations so far reviewed, Fig. 4 c presents a system using an impressed current in the link circuit, the magnitude of which depends on the required torque. The link circuit voltage changes corresponding to the motor speed and the operating mode.

A phase following inverter is provided to merely switch over the link circuit current from one stator winding to the next with the correct phase displacement. This requires inductances on the motor side that are as small as possible. To change the direction of the energy flow (transfer from motoring to braking), the polarity of the link circuit voltage is reversed. In this case, switching contacts are provided for simplification of the d.c. chopper too.



a) pulse width modulated inverter
b) d.c. chopper with pulse width modulated inverter
c) d.c. chopper with phase following inverter

Fig. 4: Circuit configurations of applicable converter systems

It has been shown that several converter systems are applicable for feeding induction motors from the existing d.c. voltage supply systems. There are, however, basic differences between systems a and b in comparison with system c, as regards the dimensioning of the traction motors and of the converter schemes. In the two systems a and b, the motors are to be designed for a small magnetising current and high stator leakage. As the opposite tendency holds true for the third system c, motors of an even smaller size can be used in this case. It has however also to be taken into consideration, that the engineering effort for a converter, including energy storage, with the circuit arrangement shown in Figs. 4 a and b is less than that in Fig. 4 c. Since on suburban vehicles problems of the converter accommodation normally exceed problems due to the motor, AEG-TELEFUNKEN applied the drive system according to Fig. 4 a for the prototype equipment described in the following section. In this connection detailed tests and simulations of the whole converter system were performed [5].

4. Three-phase drive equipment for a two-car unit of BVG

A complete equipment has been manufactured for prototype testing in the network of the Berliner Verkehrs-Betriebe (BVG). It was designed for underfloor installation so that unrestricted operation in normal passenger service can be performed to make the construction reach the production stage level. The series F-76 two-car unit equipped with the three-phase drive equipment can operate in multiple working together with vehicles of the conventional F-74 and F-76 series.

All traction motors are supplied from the d.c. line through one common pulse width modulated inverter. The schematic diagram of the drive equipment is shown in Fig. 5. The three-phase modules 2u1–2u3 are fed via the circuit breakers 1a2 and 2c1 and the line filters 2k2, 2k1. Their three-phase output supplies a bus bar system to which all four twin motors 1u1 to 1u4 are connected in parallel.

During braking operation, the series resistances 2r3–2r8 are inserted in the upper speed range. This has the effect that the inverter only needs to be designed for motoring but not for the momentary peak braking power. During motoring, these resistances are short-circuited by the contactors 2c2 and 2c3. If the line cannot – or only in part – absorb the braking energy it is fed into the braking resistances 2r1 and 2r2 electronically connected via the braking chopper 2u4. These resistances can also be utilised for controlling heating of the car with current.

The design of a three-phase module of the converter is pictured in Fig. 6. At the lower left-hand side, the plug-in units for the semiconductor devices including the necessary RC circuits and firing control units are visible. On the right bottom side, the forced ventilated commutating reactors and on the top part the line filter capacitor are located.

The converter is designed for a nominal rating of 775 kVA (560 V, 800 A). Its type rating at the maximum input d.c. voltage of 900 V amounts to 930 kVA.

Fig. 7 shows the twin motor with partly drawn out squirrel cage rotors. This twin motor drive concept is based on a suggestion by Orenstein & Koppel, with each individual motor driving one of the two axles of the bogie through a mitre gear. Both axles are thus no longer rigidly coupled as is the case for a common longitudinally arranged motor driving both axles. This allows for larger differences in the wheel diameters in a bogie. The parallel connection of several traction motors is essential with the relatively low single-motor rating. This contributes significantly to a reduction of the total engineering effort required for the converter power circuit. It has been taken into account for the electronic design in such a way that a smooth torque-speed characteristic has been chosen. This permits the current distribution between the motors to be positively influenced if the speeds of the motors differ.

Each motor is equipped with a pick-up for actual rotor speed. It is located in the end shield and scans a toothed disc at the fan wheel.

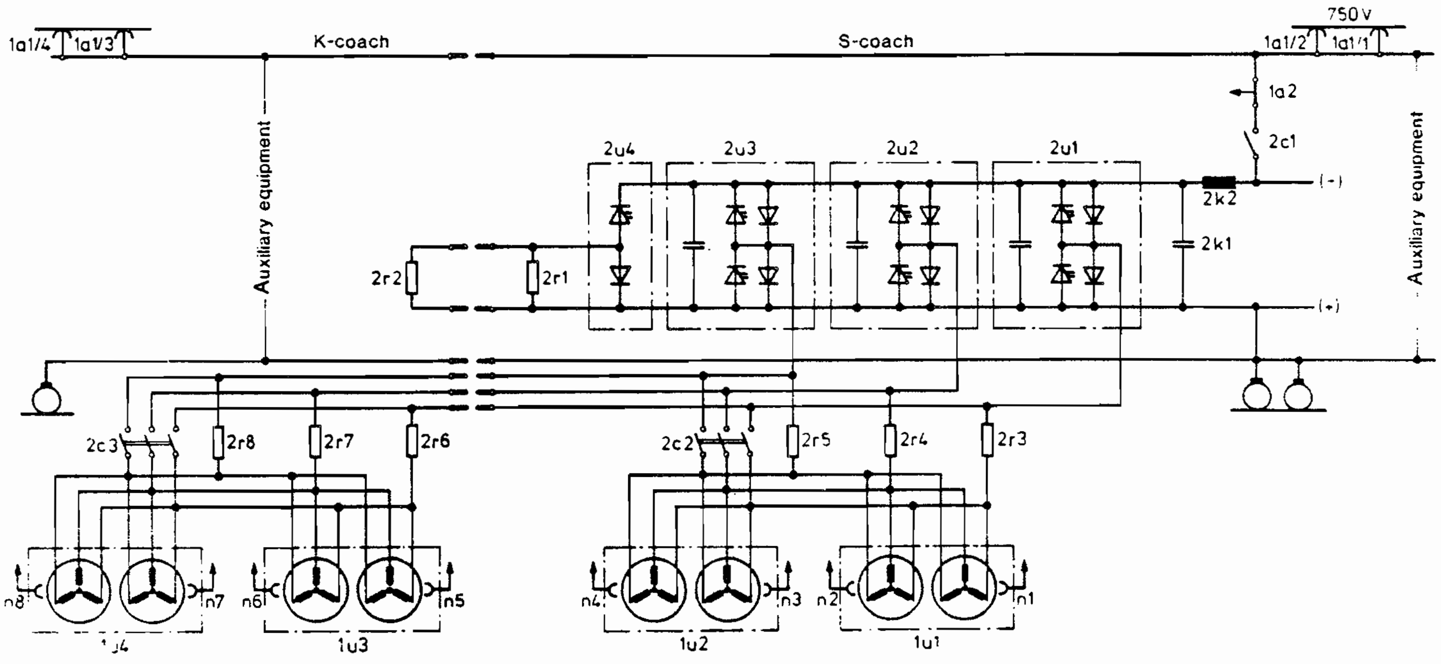


Fig. 5. Three-phase drive equipment for series F 76 two-car unit of the BVG (schematic diagram)

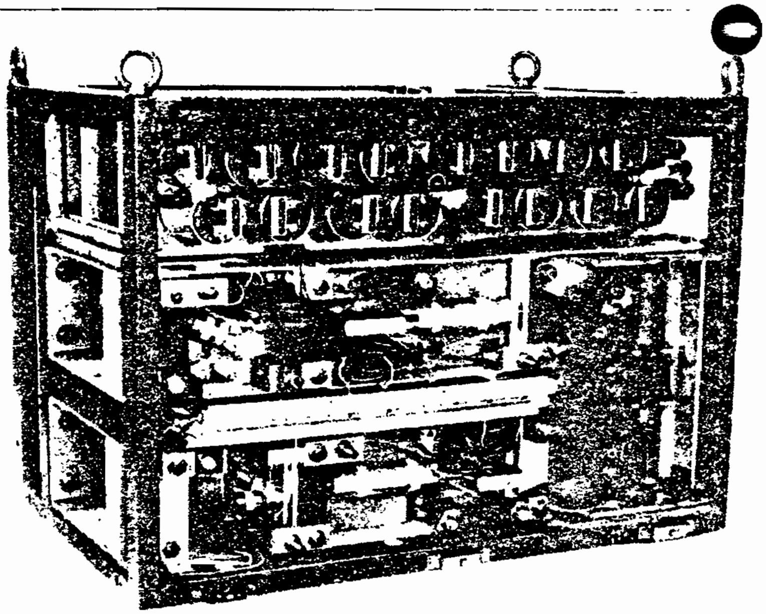


Fig. 6: Inverter phase module

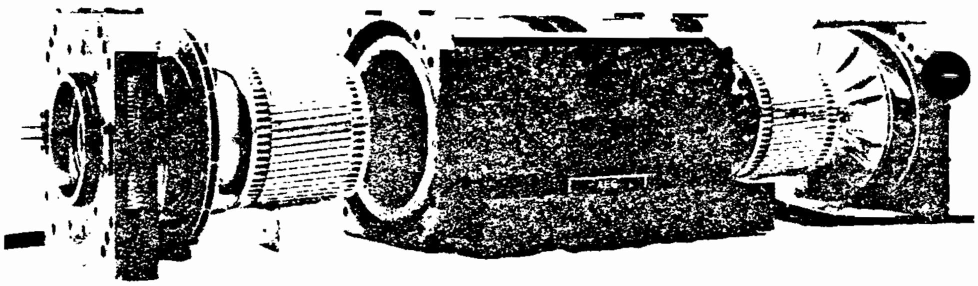


Fig. 7: Twin traction motor,
with partly drawn out squirrel cage rotors

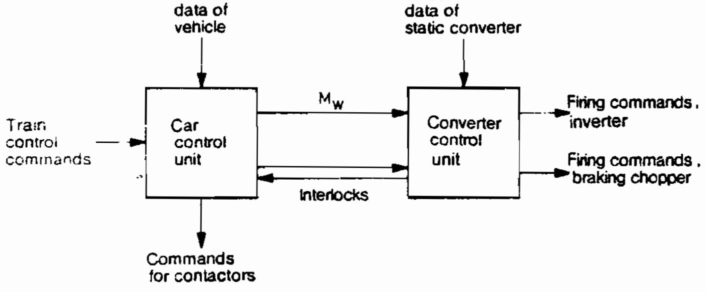


Fig. 8: Basic block diagram of control components

As shown in Fig. 8, the electronic control is subdivided into two functional groups – car control unit and static converter control. The car control unit converts the commands of the train control and the specific data of the car into signals for the converter control unit. It also includes the function generator for adaption to the characteristics of conventional vehicles. Furthermore, it provides the signals for the contactors. In the converter control unit, torque control of the drive equipment takes place in accordance with the reference signals preset by the car control unit and the actual data of the static converter. It provides firing pulses for the thyristors of the converter and the braking chopper.

Trial operation of the drive equipment described here wi[illegible]rt in 1976 on the BVG network.

5. Future outlook

Development of the three-phase a.c. drive systems is a further step that goes beyond the known and meanwhile proved d.c. chopper technology. It results in an essential reduction of mechanically actuated elements in the drive controls of suburban vehicles.

In addition, the replacement of the d.c. motor with brushes and commutator by the simple and lighter induction motor plays a role. Future operation with a higher degree of reliability and lower maintenance costs is expected to be achieved. By contrast with conventional vehicles a significant amount of energy can be saved as a consequence of the application of regenerative braking.

In the future, three-phase drive systems should be utilised on those suburban vehicles which do not need the high emergency rating for the electric brake as required for streetcars up to now. In these cases, a more favourable and thus more economical converter dimensioning can be achieved. Three-phase a.c. drive systems (including their traction motors) can gain advantages in weight in comparison to the d.c. chopper controls with the required space being about the same.

The three-phase drive systems for suburban vehicles are still in the testing stage under actual service conditions. In its development to production stage level, the two-car unit of the BVG, equipped by AEG and Orenstein & Koppel, represents a first step in this direction.

Summary

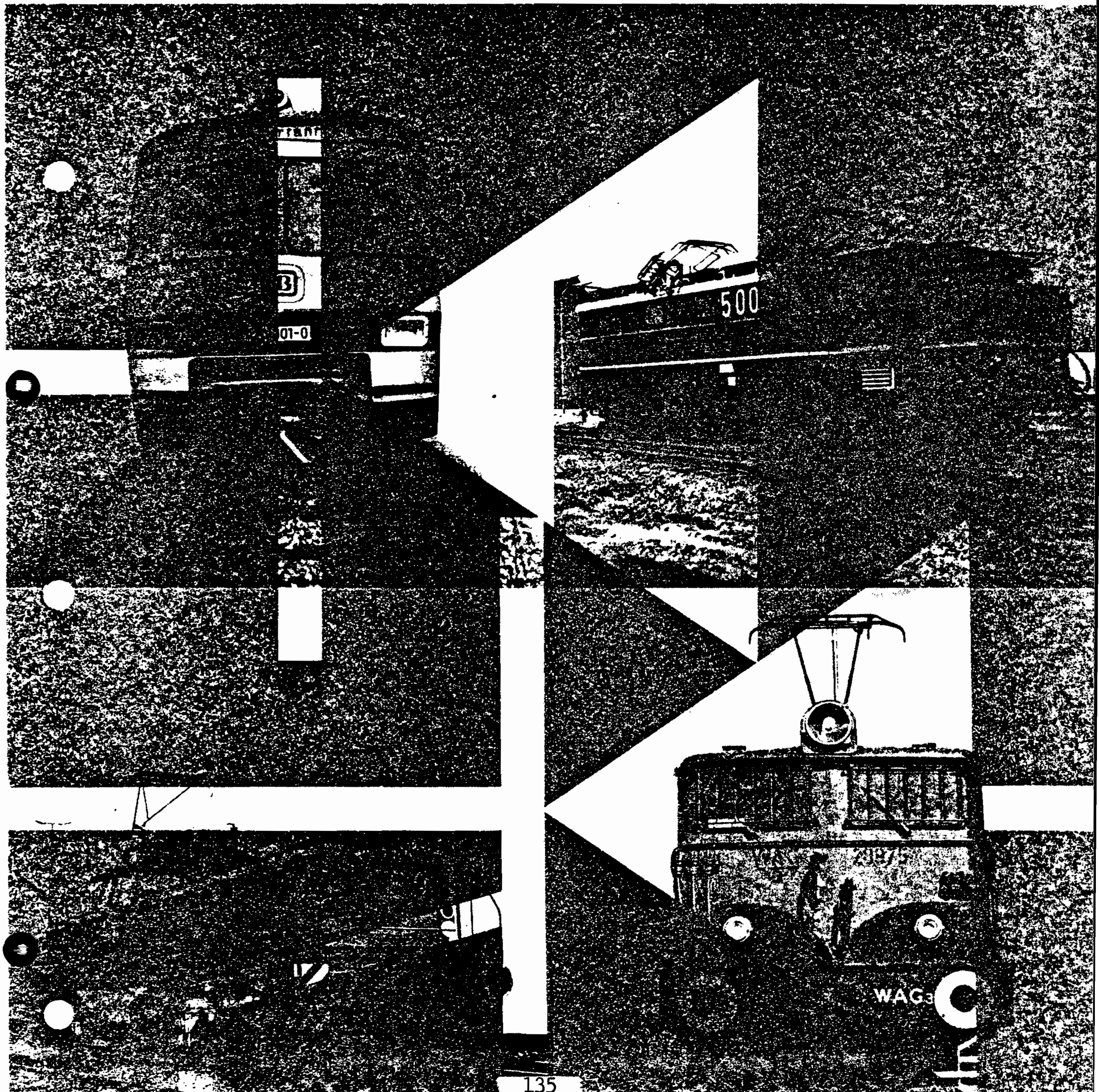
After having outlined the fundamental operating performance of converter-fed induction motors, several converter systems are described in reference to their use on suburban vehicles.

A prototype equipment is being tested on a new series F 76 two-car unit of Berliner Verkehrs-Betriebe (BVG). Individual components of this equipment are introduced.

ATTACHMENT I

AEG

Power electronics in a.c. traction vehicles



Karl-Sigismund Stötzer

UDC 621.38.026.44 : 621.335.2 621.335.42

Power electronics in a. c. traction vehicles

The development of semiconductor technology has led to a radical change in the technology of a. c. traction vehicles during the last ten years. The silicon-diode rectifier has furthered the opening up of a new and wide field of application for static convertors on traction vehicles. Since 1963, when the thyristor convertor was tried out in various circuit arrangements on a number of prototype models, this technique is now employed on a large scale for a large number of railway authorities. The progress of development from the first static-convertor locomotive to the series production of the present day is described and illustrated by some notable examples.

1. Historical development of static-convertor traction vehicles

In the past 15 years, two factors have had a major influence on the technology of electric traction vehicles:

1. the revolutionary advances in the field of static-convertor technology,
2. developments in automatic control engineering.

Advances in static-convertor technology, in particular the development of semiconductor rectifiers for high power, gave a new aspect to the question of the most favourable current system for electric traction.

In recent years, the semiconductor convertor has decided the question of system definitely in favour of 50 cycle single-phase a. c. in countries where no other traction current system had yet been established.

In connection with a large-scale experiment by the Germa[illegible] State Railway on the 50-cycle electrification in the Höllent[illegible] in 1936, AEG built the first static-convertor locomotive in the world with a six-anode, grid-controlled mercury-arc convertor with by-pass anode. This first experiment of 34 years ago was far in advance of its time, but nevertheless demonstrated important advantages of static-convertor technique and stepless control.

Based on this experience, in 1954/55 the AEG developed a series of static-convertor locomotives for opencast brown-coal mining in the Rhineland coalfields. Because of the depth of the coal seams and the unfavourable ratio of overburden to coal the planned new cuts could only be worked economically by the use of large machinery and a transport system of very high haulage capacity. For this reason, instead of the d. c. system of 1,200 V or 1,500 V previously used in opencast brown-coal mining, the new cuts Fortuna-Nord and Frimmersdorf were electrified with single-phase a. c. at 6 kV, 50 c/s.

The first static-convertor locomotives were put into service there as far back as 1955, being at that time equipped with excitron convertors of the pumpless single-anode tank type. In these locomotives, however, the latest practice in automatic control was employed, including stepless voltage control by a combination of tap changing and grid control. The convertors could be changed over to line-commutated inverted operation, so that current-controlled regenerative braking with full locomotive power from top speed and w[illegible] full braking force to standstill was possible. These first convertor locomotives of the Rheinbraun-AG (RAG) provided very extensive and valuable experience for electric traction, especially with respect to the control equipment.

2. Diode rectifiers on traction vehicles

Making use of this experience, AEG developed the dual-frequency locomotive E 182.001 for the German Federal Railway (DB) during 1958 to 1960. This locomotive is in service in the Saarbrücken-Metz region; crossing the frontier it can be fed either from the DB network at 15 kV, $16^2/_3$ c/s or from the SNCF[1]) network at 25 kV, 50 c/s.

On this locomotive the AEG used for the first time silicon-diode rectifiers with a power of about 5 MW in conjunction with a low-voltage tap-changer. The locomotive was also equipped with stepless starting control gear employing transductors. This allows continuous transition from one step to the next by excitation in opposite directions of the two transductors designed for the full step voltage by means of a special control equipment and amplifier stage. Because of this stepless transductor starting gear it was possible to equip the locomotive with automatic tractive effort control.

3. Thyristor convertors on traction vehicles

3.1. General

An important advance in the design of stepless starting gear was possible when the first power thyristors became available. Being a silicon controlled rectifier, the application of the thyristor is similar to that of the grid-controlled single-anode mercury-arc rectifier, but it has the great advantage, especially for traction work, of requiring no supplementary equipment for excitation and temperature control and of being ready for immediate service without previous heating up even when the outside temperature is very low.

It was especially the necessary heating-up which was a serious obstacle to the general use of the mercury-arc rectifier for traction duty. The thyristor convertor first made possible the introduction of completely contactless control gear on a wide basis.

Whereas with the conventional single-phase a. c. traction vehicles and those with tap-changers, diode rectifiers and undulated-current motors, the amplitude of the voltage fed to the traction motors is varied, with thyristor-convertor vehicles the voltage is varied by phase control, with the firing point of the thyristors being delayed in each half cycle (Fig. 1).

Naturally phase control immediately raises the question of power factor, since it is well known that in addition to the commutating and distortion reactive power a displacement reactive power is also required when the pulses of the gates are delayed by the angle α. This displacement reactive power can be considerably reduced by the use of suitable circuits with consequent improvement of the power factor. Such a possibility is offered in the so-called semi-controlled rectifier bridge, like the unsymmetrical semi-controlled bridge illustrated in Fig. 2.

The special feature of this circuit is that instead of the otherwise usual arrangement with controlled cells in all four arms of the single-phase bridge, two arms are equipped with normal diodes and are therefore not controlled. The diodes make possible so-called *freewheeling* (as indicated by the current arrow I in Fig. 2) for the direct current, which because of the usually high smoothing inductance wants to flow even after the network voltage has passed through zero and can thus easily commutate, e. g. from thyristor *p* 1 to diode *n* 1. The network current flowing through thyristor *p* 1 is therefore immediately suppressed and so imposes no further load on the network during the negative half wave, which would be equivalent to additional consumption of reactive power. After the firing of the other thyristor arm *p* 2, the freewheeling current is suppressed and the load current is again drawn from the network. The fundamental wave of the network current is therefore less displaced in phase with respect to the voltage and the power factor is thus considerably improved.

Nowadays, whenever operation of phase-controlled convertor-fed drives is discussed, the question of power factor is a major topic. That the power factor during starting is not of such great importance as is often thought is seen most clearly when the power factor is plotted as a function of the speed (Fig. 3). With conventional a. c. traction units (characteristics *4* and *5*), the full transformer secondary voltage is only reached at top speed, whereas with the a. c.–fed rectifier traction unit the nominal voltage of the traction motor, i. e. the full control of the voltage, is reached at a speed of $0.5\,v_{max}$. Above $0.5\,v_{max}$ with full control, field

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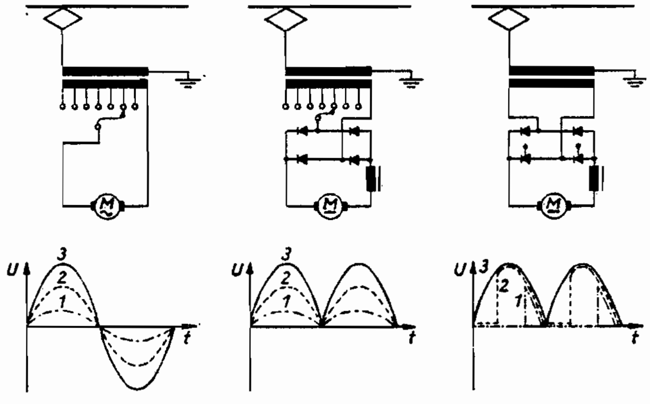
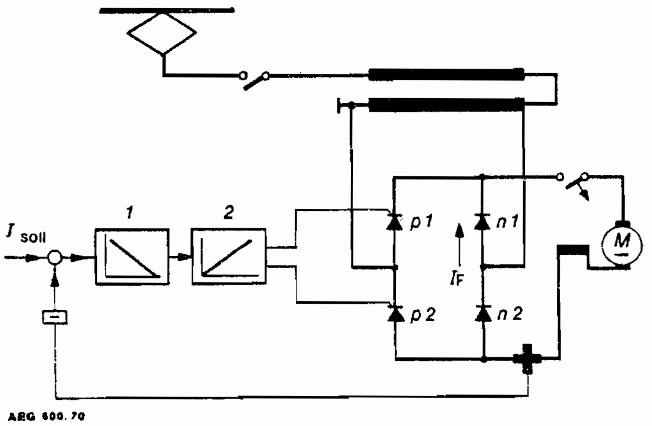
[1]) SNCF Société National des Chemins de Fer Français



a.c. amplitude control   d.c. amplitude control   d.c. phase control

Fig. 1. Voltage control of traction motors



1 *I*-controller
2 Pulse transmitter
p 1, *p* 2 } Thyristor arms
n 1, *n* 2 } Diode arms

Fig. 2. Unsymmetrical semi-controlled two-phase bridge connection

$\frac{v}{v_{max}}$	Relative speed
$\frac{U_d}{U_{d0}}$	Degree of control (thyristor-converter locomotive), characteristics *1* to *3*
St	Phase control
F	Field weakening
A	Starting region
1	Fully-controlled bridge
2	Semi-controlled bridge
3	Two semi-controlled bridges in sequence connection
4	A.C. motors with h.v. tap-changer
5	A.C. motors with l.v. tap-changer

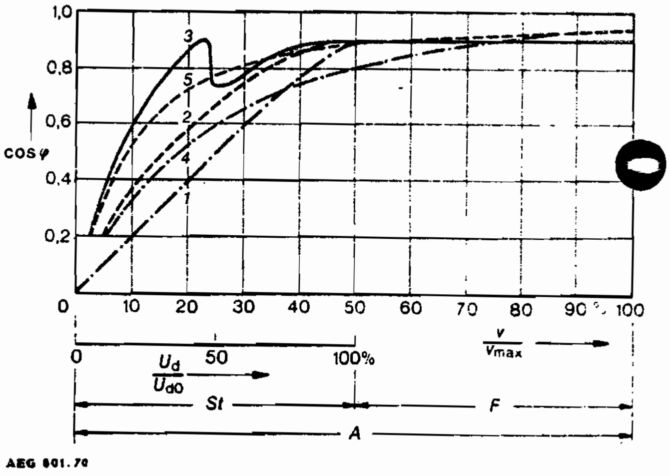


Fig. 3. Power factor with different locomotive control equipments

weakening is employed. The range from 0 to 0.5 v_{max} is passed in such a short time as compared with the normal running schedule that the extra consumption of reactive energy due to the displacement reactive power during the starting period is quite insignificant. Characteristic *2* clearly shows the saving in reactive power by the use of a semi-controlled bridge instead of a fully-controlled bridge (characteristic *1*). The sequence control of two semi-controlled bridges connected in series (characteristic *3*) is already superior to the conventional a. c. control schemes with h. v. or l. v. tap-changer (characteristics *4* and *5*). Phase-controlled convertor drives are therefore quite competitive with the conventional locomotive control equipments also as regards power factor.

The principle of sequence control can in theory be continued indefinitely by further subdivision into, for example, three or four semi-controlled bridges to be fully opened one after the other. It is obvious, however, that the saving in reactive power would be quite out of proportion to the extra cost of the transformer and rectifier.

3.2. Prototype models

By the end of 1963, the AEG had supplied the first thyristor convertors in semi-controlled bridge connection for two motor coaches of Series 425 of the German Federal Railway in the Heidelberg region and for one motor coach of the SNCF in Savoy. The d. c. power per motor coach was about 800 kW.

The good operating experience obtained with these first thyristor convertors was an encouragement to extend this technique to locomotives of high power. In 1964/65, the AEG converted one of the excitron-convertor locomotives supplied some ten years earlier to thyristor-convertor equipment. The working conditions of these brown-coal opencast-mining locomotives are particularly onerous, as not only have they to pull very heavy trains on steep gradients but regenerative braking with full locomotive power is also employed. In addition, during shunting by UHF radio remote control [illegible] the train is being loaded under the excavator, the conve[illegible]s are operated in anti-parallel connection. With this first thyristor-convertor locomotive in the world it was possible to demonstrate that even line-commutated inverted operation was practicable with absolute reliability.

Because of regenerative braking the two armature convertors have thyristors in all four arms; but during normal running they are operated like the semi-controlled bridges already mentioned, thus saving reactive power. During regenerative braking, all four bridge arms are controlled.

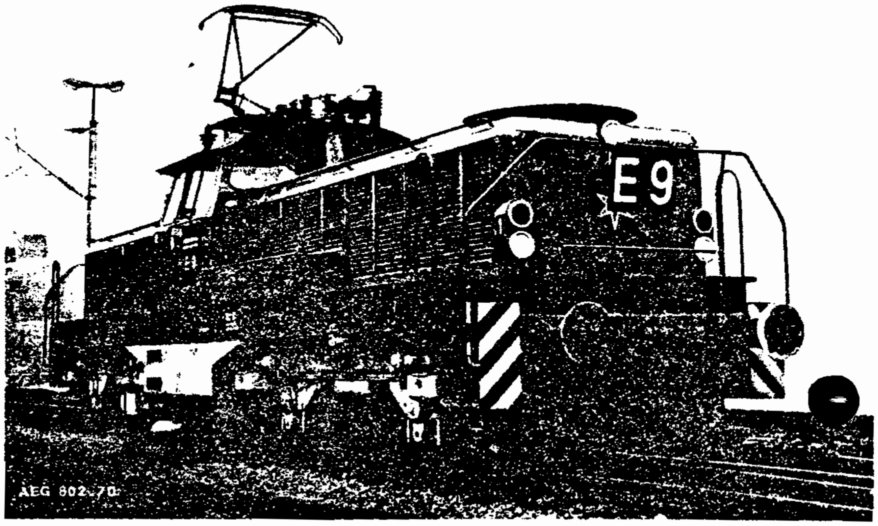


Fig. 4. Bo′Bo′ industrial locomotive of the Hibernia-Bergwerksgesellschaft, 4 x 180 kW (1-hour)

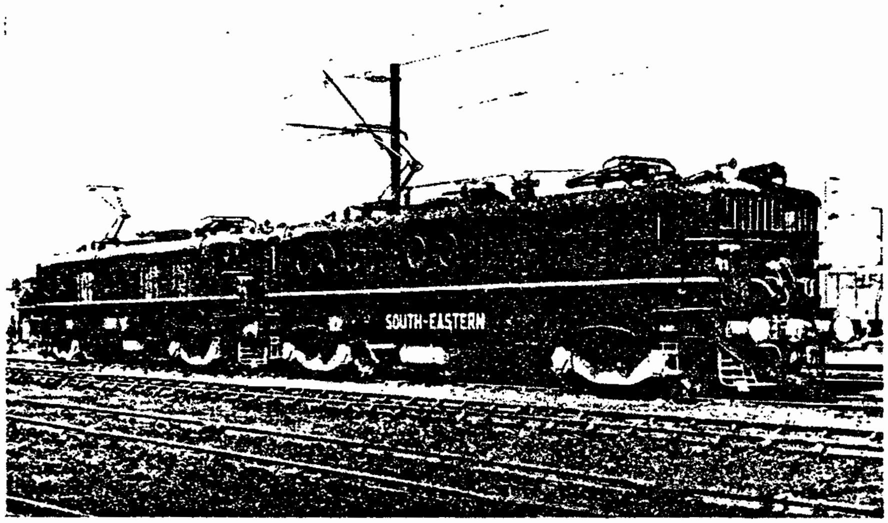


Fig. 5. B′ B′ thyristor-convertor locomotives of the Indian Railways, 2 x 1100 kW (continuous) per locomotive

Regenerative braking enables power of the order of the maximum running power (about 3,000 kW) to be returned to the network, which would have been impossible with dynamic braking because of the size of the necessary resistors. A particular advantage is, however, that it is possible to brake with full braking force down to standstill, which is impossible with dynamic braking.

Also in hard-coal mining industrial works are now electrifying their railway systems at 50 c/s, and are employing convertor locomotives. As electrified sidings of the Federal Railway exist almost everywhere, these locomotives are often designed as dual-frequency units for 50 c/s and $16^2/_3$ c/s (Fig. 4). AEG-TELEFUNKEN have supplied for Rheinstahl-Bergbau four Bo′Bo′ locomotives, the Co locomotives and three Bo locomotives as well as twelve Bo′Bo′ locomotives for Hibernia.

The locomotives for Rheinstahl-Bergbau are equipped with thyristor convertors in semi-controlled bridge connection. As there is a separate rectifier for each traction motor, the traction motors as well as the other apparatus and the rectifiers are interchangeable in spite of three different types of locomotives. By contrast, on the Hibernia locomotives all four motors are fed from a common rectifier through a busbar and equipped with separate field rectifiers to achieve uniform load sharing. Both types of locomotive have also a battery for use on sections of track where there is no overhead contact wire. For battery operation of the Rheinstahl locomotives the d. c. energy is passed through a separate pulse inverter and then through the phase-controlled traction rectifier. In the Hibernia locomotives the battery voltage is pulsed, the thyristors of the armature rectifier being used as d. c. control elements after suitable changeover.

In the past twelve years, AEG-TELEFUNKEN, as a member of the 50-cycle Group, have participated in the delivery of more than 400 locomotive equipments to the Indian Railways. The first 212 locomotives were still equipped with mercury-arc rectifiers. It was quickly found, however, that because of their sensitivity to temperature mercury-arc rectifiers were not the ideal form of static convertor for these locomotives, because in the tropical climate of India when locomotives had been at standstill for some time the machinery compartment reached a temperature of over 70 °C in a few minutes, causing the temperature protective device of the tanks to operate. For this reason, in 1963 the Indian Railways began to specify silicon rectifiers in their further orders for locomotives. AEG supplied silicon rectifiers for 161 locomotive equipments as well as rectifier components for more than 190 further rectifiers made in India under AEG licence.

As a result of their experience with thyristor convertors on motor coaches of the German Federal Railway and SNCF, in 1964, i. e. while the RAG locomotives 500 were still being converted, AEG received an order from the Indian Railways to equip two locomotives as experimental prototypes with thyristor convertors for running and regenerative braking (Fig. 5).

In these locomotives, as in the case of the first thyristor-convertor locomotive of the RAG, all switching devices subject to wear in the power circuit were eliminated. There are no tap changer, field-weakening contactors or field-weakening resistors and also no reversers and changeover commutators. Continuous speed control is effected by voltage control with automatic current regulation. Field weakening is also continuous, employing no contacts. Automatic anti-slip protection by means of voltage and current comparison is also provided. Reversing and changeover commutating is effected by field reversal with the aid of rectifiers in anti-parallel connection for field excitation.

Thyristor-convertor technique found wide application by the German Federal Railway when multi-system locomotives were ordered for traffic across national frontiers.

For international through-traffic, locomotives are required which can take supply from $16^2/_3$ c/s and 50 c/s a. c. networks and also from d. c. networks with contact wire voltages of 3,000 V and 1,500 V, so that, for example, a train can run from Amsterdam to Rome without change of locomotive. The high one-hour rating of 3,200 kW required for these four-acle locomotives necessitated much consideration as to the practicability of operation on the d. c. systems, because conventional technique raises serious problems for the traction motors. In the first place, these must be insulated for 3,000 V and designed for 1,500 V at the commutator and in addition they must commutate satisfactorily at these high voltages also during operation with undulated current and a high degree of field weakening.

Fig. 6. Local-traffic trainset ET 420 for Munich city (S-bahn) transit system 12 x 200 kW (1-hour)

AEG-TELEFUNKEN succeeded in overcoming all these difficulties by extensive application of the new technique of thyristor convertors. In addition to the phase-controlled thyristor convertors for varying the voltage in the two a. c. systems, forced-commutated thyristor inverters were provided before the main transformer so that the main transformer could be fed with a. c. even when running on d. c. systems and accordingly on the rectifier side the speed control is the same in all four systems. Attention may be drawn to the detailed description of these locomotives [8] and to a brief description of operating experience [9].

As a result of the extensive experience obtained with these locomotives, thyristor-convertor technique achieved its final breakthrough in 1967 with the booking of the order for 120 Series 420 three-car local-traffic trainsets with the German Federal Railway for the city (S-Bahn) transit system in Munich. These 120 trainsets, of which the AEG prototype (Fig. 6) was put into service in the autumn of 1969, are equipped with unsymmetrical semi-controlled thyristor-convertor bridges in sequence control (two successively controlled bridges in series). AEG-TELEFUNKEN were entrusted by the Federal Railway with the general direction for the whole complex *Power and Control Electronics* and supplied the whole of the control electronics and automatic control equipment as well as parts of the power electronic equipment for the two other electrical firms taking part in the contract. With the putting into service of the prototype trainset it was possible to demonstrate that the concept envisaged for the whole of the electronic equipment operated satisfactorily, providing a stepless and high starting acceleration with good control characteristics. Attention is drawn to the detailed description of the electrical equipment elsewhere [10].

4. Summary and future prospects

The problem of the commutatorless traction motor has been a subject for study for many years. For a. c. traction vehicles, in particular for $16^2/_3$ c/s, there seem to be no immediate prospects of practical application because of the present very high cost of the commutating and smoothing equipment for the d. c. intermediate circuit of the pulse inverter. Nevertheless it is necessary to pursue this development at least in the special field of the d. c.–fed traction unit. Already, at the International Transport Exhibition in Munich in 1965, AEG was able to exhibit a model suitable for a power of about 400 kW with a commutatorless nose-suspended motor, which was fed from a traction battery through a pulse inverter. The successes already achieved in the field of power and control electronics for traction work provide encouragement to continue this development. AEG-TELEFUNKEN can claim to be pioneers in the new technique for traction work and with the exception of the commutatorless motor have already introduced into practical traction service:

stepless starting control,
automatic control of tractive effort,
automatic voltage control with current limitation,
regenerative braking on static-convertor locomotives and forced-commutated inverters of high power.

The putting into service, of the Series 420 prototype trainsets equipped with AEG electronic equipment in autumn 1969 and the intensive proving tests carried out since have demonstrated that phase control with thyristor convertors is now past the development stage and that trainsets thus equipped can be put into service even in a large series without appreciable difficulties.

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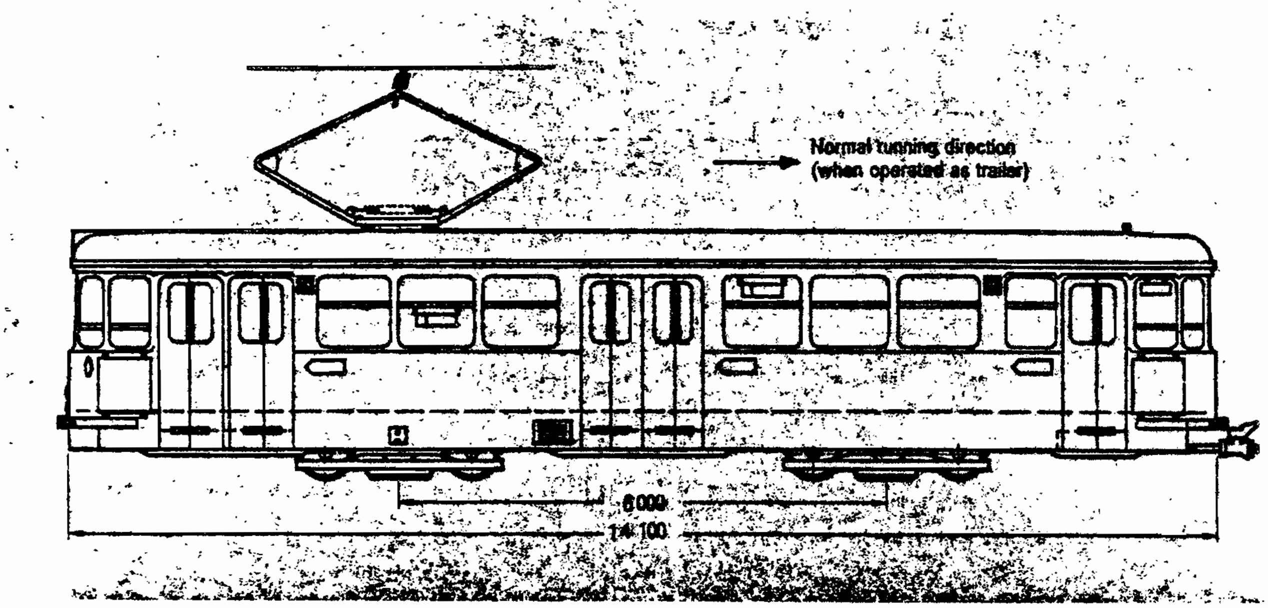
ATTACHMENT J

SIEMENS

Experimental Car with Three-Phase Drive of the VAG Nuremberg



Type of car	Unidirectional trailer with one motor bogie
Wheel arrangement	2'B'
Track gauge	1435 mm
Length of car	14.1 m
Width of car	2.34 m
Bogie pivot pitch	6 m
Bogie wheel-base	1.8 m
Tare weight	14900 kg
Passenger capacity	29 seated plus 110 standing
Line voltage	600 V d.c. (24 V d.c. auxiliary system)
Rated power	185 kW/60 min at 48 km/h
Max. speed	60 km/h
Secondary brakes	4 track brake magnets, 600 V 3 solenoid-operated disc brakes

The experimental car with 3-phase drive is a motorized trailer used for field-testing of the thyristor-controlled three-phase motor drive under the harsh conditions prevailing in urban transport systems. The new drive equipment was fitted when the trailer underwent general inspection in November 1975. The pantograph collector and the provisional driver's controls fitted in the tail section permit test runs of the car as an independent unit. Normal operation is carried out in coupled running with motor cars fitted with SIMATIC control equipment permitting train control in line with VÖV (German Association of Public Transport Undertakings) Recommendations 6.325.1 (e.g. the motor car No. 208 of VAG Nuremberg.)

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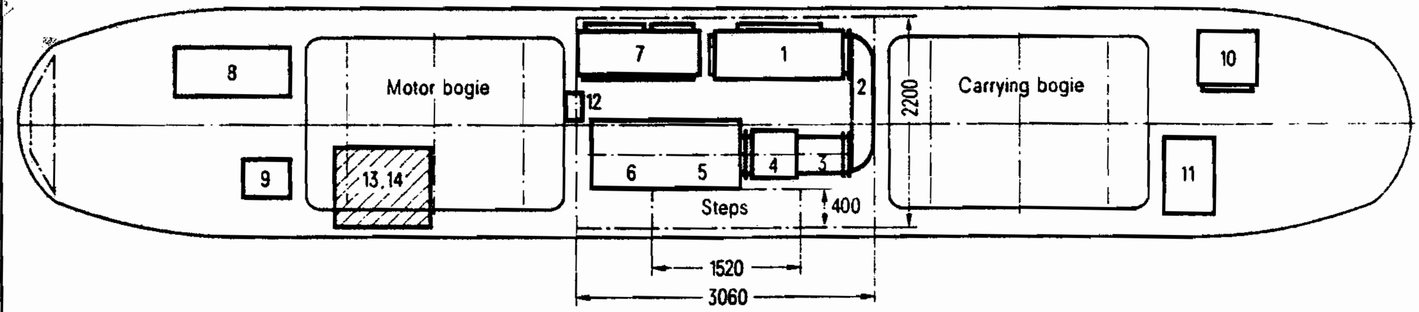
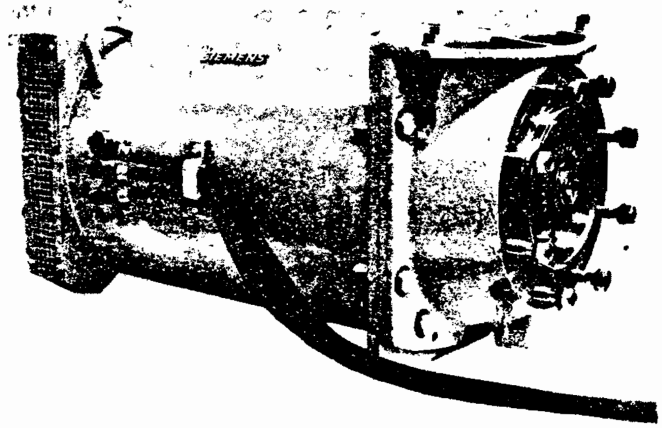


1 D.C. chopper
2 Air duct
3 Fan
4 Line reactor
5 D.C. link reactor

6 Brake resistors
7 Switchgear
8 Line capacitor
9 Main breaker
10 Battery box

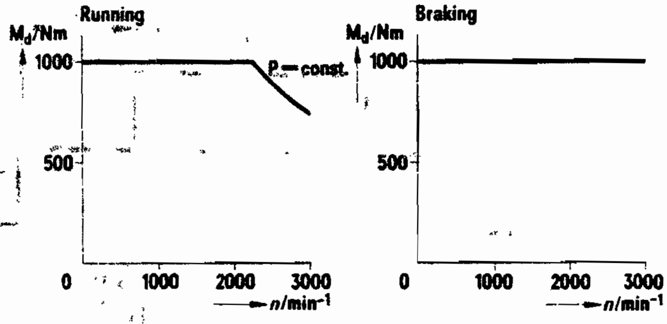
11 M-G set
12 Traction motor terminal box
13 Inverter
14 Car control unit

Items 1 to 12: underfloor
Items 13 and 14: in car body ▨



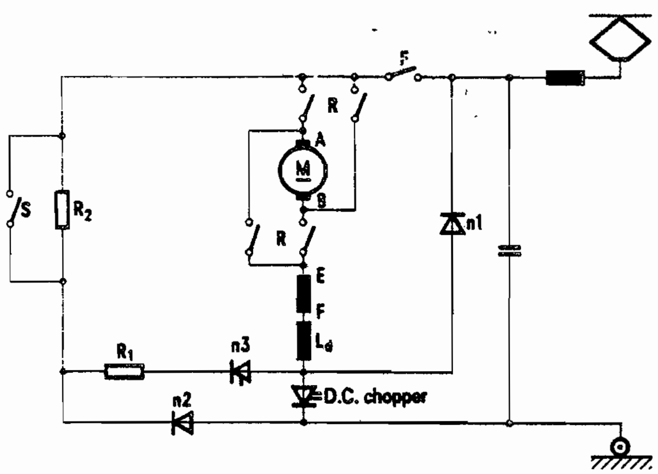
Three-phase traction motor

The **traction motor** is a self-ventilated 4-pole induction motor with squirrel-cage rotor, suited for 0 to 100 c/s, 380 V 3-ph. a. c., 185 kW/60 min, 3000 rev/min
Insulation class F
Rheinstahl-Düwag 2-axle longitudinal drive
Gear ratio 41:7
Wheel rim diameter 670/560 mm (new/worn)

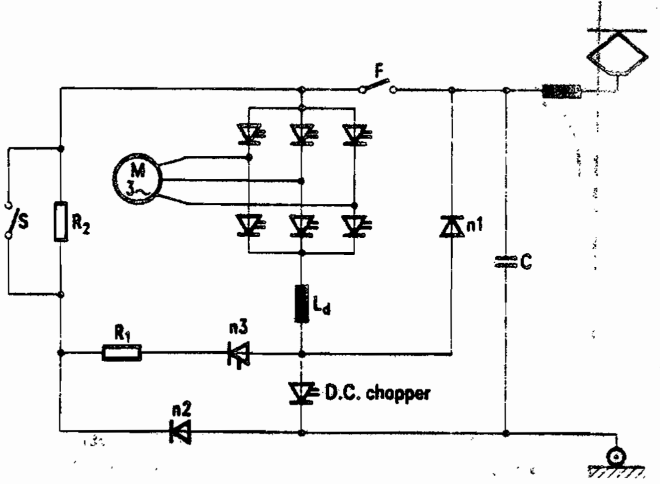


Torque/speed characteristics of VAG Nuremberg 3-phase drive

The permissible-load diagram of the three-phase drive enables starting accelerations and service braking rates of up to 1.0 m/s² to be attained with only one motor. Twice this value applies to normal motor cars having 2 motor bogies.



Power circuit of a motor car using d.c. chopper control

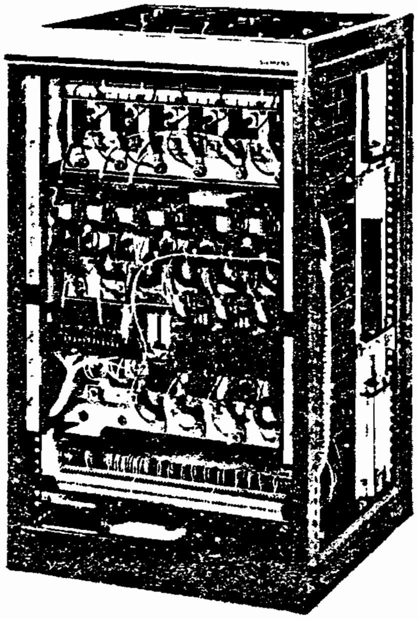


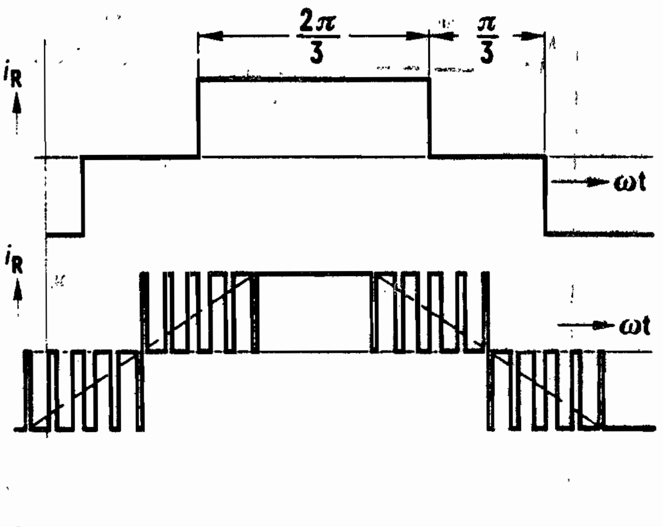
Power circuit of a 3-phase a.c. drive for d.c.-operated rail vehicles

The 3-phase a.c. drive is based on the proven d.c. chopper circuit for commutator motors and mixed regenerative/rheostatic braking (left-hand diagram), the only difference being that the series-wound commutator motor plus reverser is replaced by an inverter and 3-phase induction motor (right-hand diagram). There are no new problems regarding compatibility of the car control equipment with trackside and other stationary systems, or regarding regenerative braking.

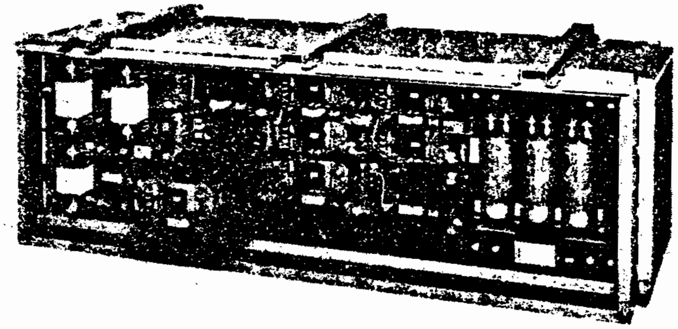
The employment of a current source inverter and phase-sequence turn-off makes for a straightforward inverter circuit arrangement and highly compact component units. The inverter output frequency depends on the gear ratio and maximum speed, the range being 0 to 100 c/s in this case. Torque pulsations at low frequencies are prevented by current pulse modulation (see illustration below).

Inverter using phase-sequence turn-off
600 x 600 x 1000 mm
512 V d.c., 580 A d.c./300 kVA
0-120 c/s

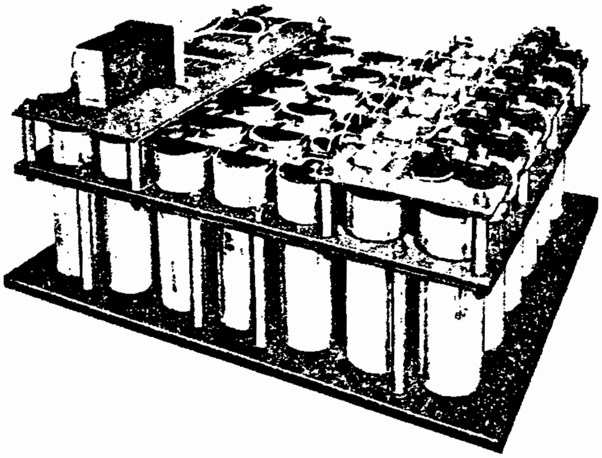




Pulsed operation of the inverter



D.C. chopper regulator using P thyristors
600 V, 210 kW, 250 c/s



Line capacitor bank with capacitor monitoring system
and d.c. line-voltage measuring transformer

The d.c. chopper, line filter and car control unit used have already been field proven in similar applications.

Advantages of the new drive concept

- No commutator or sliprings in the traction motor
- Electrical equipment weight same as with d.c. chopper regulator drives
- Motor bogie weight reduced
- Maintenance requirements even lower than with d.c. chopper regulator drives
- Standstill current of drive does away with uphill starting problems.

ATTACHMENT K

SIEMENS

D.C. Operated Double Unit with A.C. Three-Phase Drives and Regenerative Brake of the Vienna Underground

Type of car	semi-permanently coupled bi-directional double unit of light alloy construction with pneumatic suspension
Train formation	train operation with cars equipped with d.c. drives possible
Wheel arrangement	B'B'+ B'B'
Track gauge	1435 mm
Tare weight	55 t
Passenger capacity	98 seated + 182 standing (4 pers./m^2), max. 400 passengers
Laden weight (max.)	83 t
Maximum speed	80 km/h
Supply system	750 V/-30 %, +20 % d.c. (3rd. rail system)
Traction motors	A.C. threephase asynchronous motor type, two-axle longitudinal drive (all wheels driven), 4 x 200 kW/470 V/50 Hz/1000 rev./min. max. speed in service: 2800 rev./min.
Gear ratio	5.38:1
Wheel diameter/Floor height	900 mm new, 820 mm worn/1050 mm above top of rail
Propulsion system	D.C. current link converter comprising d.c. chopper for current control and inverter (phase-sequence extinction) for speed control, self-excited regenerative and rheostatic brake controlled by the converter
Auxiliary voltages	110 V d.c. and 24 V d.c.
2nd service brake	electropneumatically-controlled air brake (one brake disc per axle)
Safety brake	indirect, graduated-release air brake system, 50 % of all air brake cylinders are of the spring-applied, air-released type.

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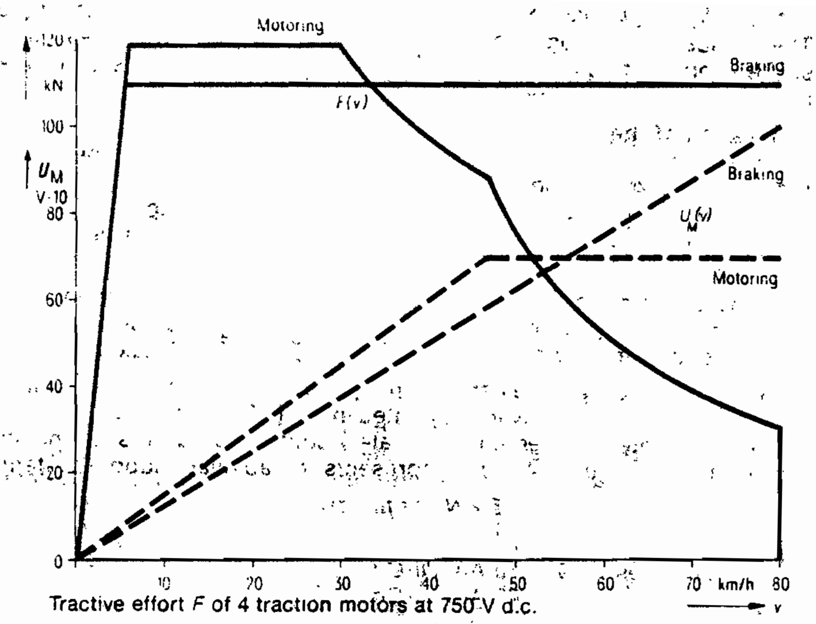
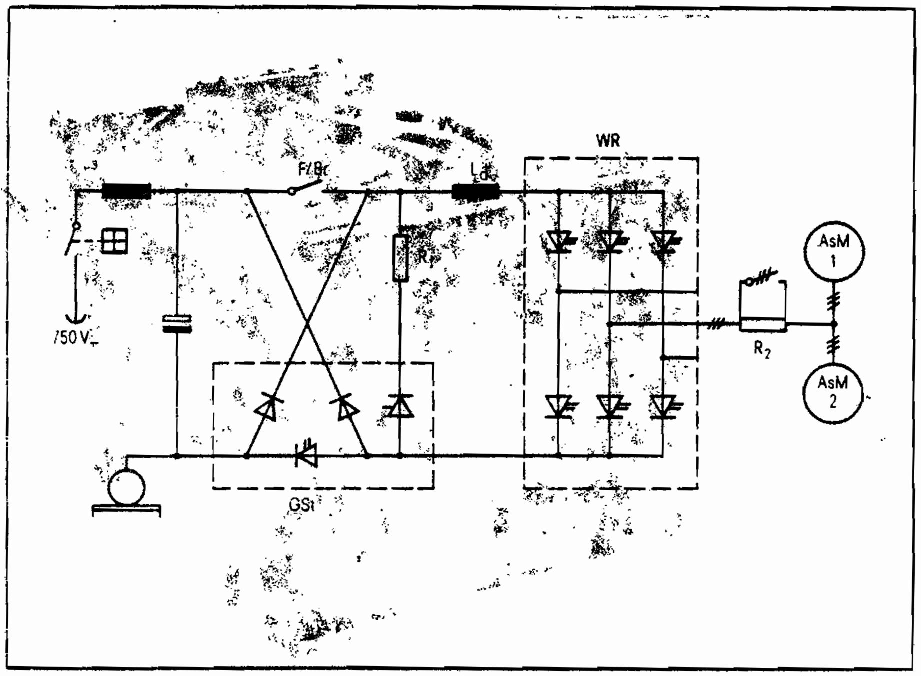


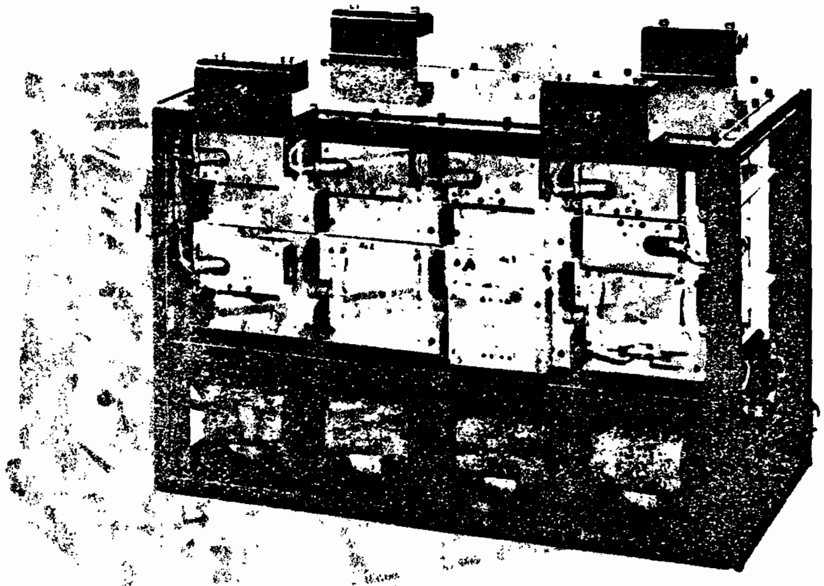
Tractive effort F of 4 traction motors at 750 V d.c.
U_M (v) Characteristic of motor voltage in principle.

Tractive effort- and braking effort diagra
of the double unit equipped with 4 a.c
threephase drives



F/BR	motoring/braking contactor
GSt	d.c. chopper
WR	inverter
L_d	smoothing reactor for current link circuit
R_1	braking rheostat
R_2	series braking resistor
AsM	asynchronous traction motor

Schematic circuit diagram of a single unit
(operation of a single unit is possible).



750 V d.c./1150 A max., 600 A continuous.
250 Hz, pulse-width control.

D.C. chopper

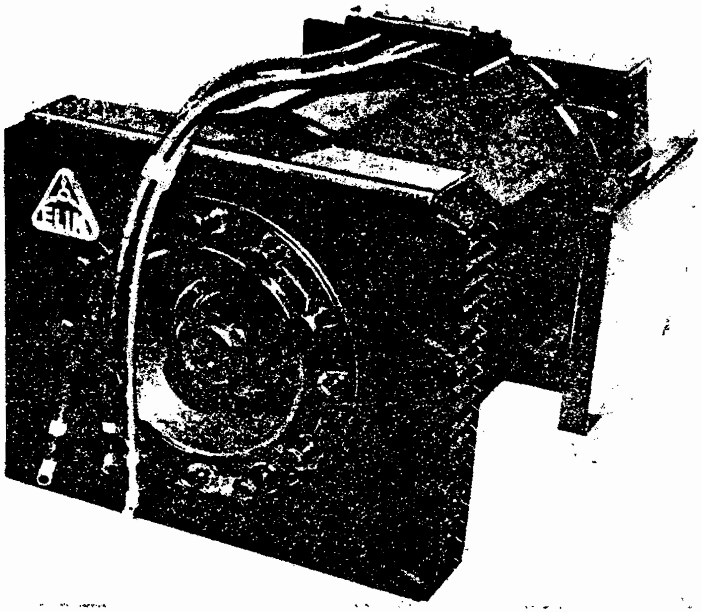
system: Westinghouse, pneumatic system: Knorr, couplings: Scharfenberg).
The air-suspended bogies are equipped with 2 Thyssen-axle gear drives, 4 air-suspension bellows and are linked to the car body by means of a roller centre bearing.

Installation of the electrical equipment:
Major elements of the power electronics are installed in equipment cubicles being mounted underneath the car body, other parts of the propulsion equipment and the remaining electrical devices are built-in boxes forming an integral part of the underframe, the electronic motoring/braking control system as well as the traction motor control is located below a car seat at the shortcoupler end.

Lighting of the motorcar: Supply is taken from the battery system using individual transistor inverters to ensure continuous and flickerless light. Two continuous luminous rows maintain an illumination intensity of 300 Lux.

Only one common set of electrical and pneumatic equipment is installed per double car. A static thyristor-converter (located in the B-car) working as d.c./d.c. converter providing 2 potential-free and separately controlled outputs for the low-voltage system 110 V d.c. and 24 V d.c. represents the auxiliary supply system.

rating:	110 V, 5.5 kW continuous 24 V, 1 kW
storage batteries:	110 V, 50 Ah, Ni-Cd 24 V, 70 Ah, Ni-Cd



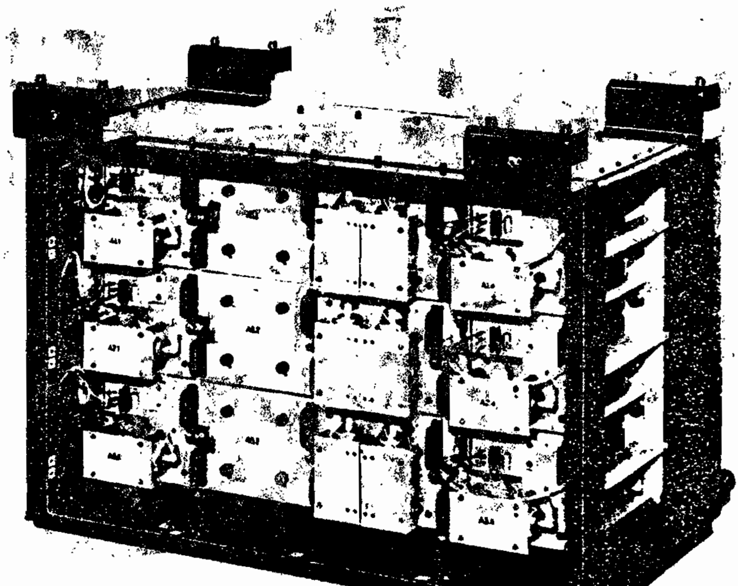
A.C. threephase traction motor
type MCF-031 V06

The traction motor was developed and built by ELIN, Vienna for the Vienna Underground on behalf of the Traction Division of Siemens AG

1-hour rating:
200 kW, 470 V, 50 Hz, 1000 rev./min.
280 kW, 700 V, 75 Hz, 1500 rev./min.

the traction motor is self-cooled, insulation class F.

Traction motor for two-axle longitudinal drive

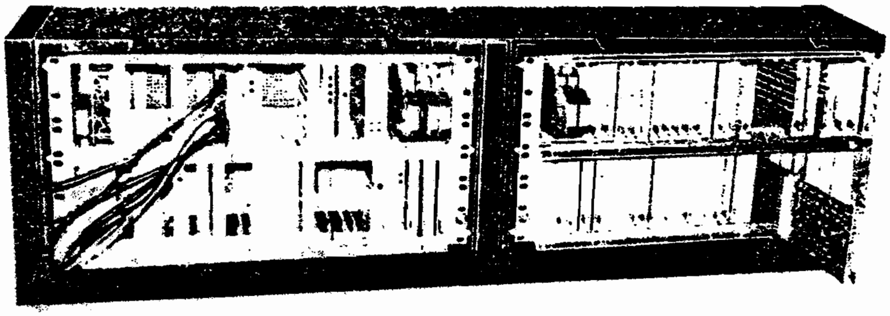


D.C. 675 V/1150 A max.
A.C. 700 V/50 Hz/900 A

frequency 0.2-140 Hz
max rating: 625 kW/900 kVA
nominal rating: 780 kVA

One inverter feeds two parallel-connected traction motors

Inverter using phase-sequence extinction



Control device

▲

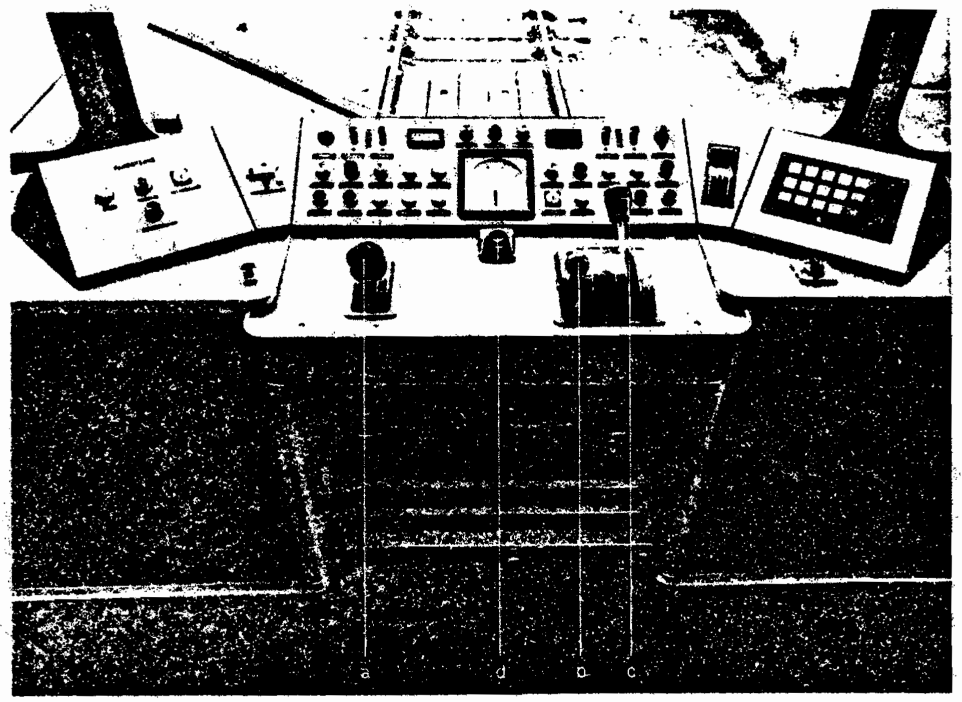
Car control system

motoring/braking operation based on train control signals, current control via d.c. chopper, anti-skid protection, weight-transfer compensation.

▲

Motor control

based on the TRANSVECTOR® principle, frequency- and flux control via inverter, starting assisted by current pulses.



The car control system is prepared to ensure automatic train operation

1. Manual driving
    a) control button combined with deadman device
    b) pre-selection of permanent operational steps
    c) brake lever
2. Automatic operation
    d) starting push buttom
3. Special operation for measurements during commissioning and demonstration purposes using a continuous motoring/braking signal transmitter.

Automatic control

The train will be controlled via CATC (Continuous Automatic Train-Running Control) from the starting signal to the next stop in a station by simply operating buttons on the drivers desk.
Motoring and braking signals will be received via car pickup coils (installed at the bogie) from track antennas — short-length cable loops. The loops are installed according to ORE-B2 (2 wires in a distance of 40 cm in the centre of the track). The system is suitable to revers trains in terminals without driver.